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# Drone-enabled bridge inspection methodology and application

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ABSTRACT

The field of Civil Engineering has lately gained increasing interest in Unmanned Aerial Vehicles (UAV), commonly referred to as drones. Due to an increase of deteriorating bridges according to the report released by the American Society of Civil Engineers (ASCE), a more efficient and cost-effective alternative for bridge inspection is required. The goal of this paper was to analyze the effectiveness of drones as supplemental bridge inspection tools. In pursuit of this goal, the selected bridge for inspection was a three-span glued-laminated timber girder with a composite concrete deck located near the city of Keystone in the state of South Dakota (SD). A drone, a Dà-Jiāng Innovations (DJI) Phantom 4, was utilized for this study. Also, an extensive literature review to gain knowledge on current bridge inspection techniques using drones was conducted. The findings from the literature review served as the basis for the development of a five-stage drone-enabled bridge inspection methodology. A field inspection utilizing the drone was performed following the stages of the methodology, and the findings were compared to current historical inspection reports provided by the SD Department of Transportation (SDDOT). Quantified data using the drone such as a spalled area of 0.18 $m^2$, which is identical to the measurement provided by the SDDOT (0.3 m by 0.6 m), demonstrated the efficiency of the drone to inspect the bridge. This study detailed drone-enabled inspection principles and relevant considerations to obtain optimum data acquisition. The field investigation of the bridge demonstrated the image quality and damage identification capabilities of the drone to perform bridge inspection at a lower cost when compared to traditional methods.

## 1. Introduction

The American Society of Civil Engineers (ASCE) has regularly studied the structural performance of the nation's infrastructure, including bridges. The most recent ASCE report card for America's infrastructure, released in December 2016, specified that approximately 9.1% of the nation's bridges were classified as structurally deficient for a letter grade of $C^+$ [1]. Although the number of deficient bridges has declined from 11% to 9.1% in the last three years [2], there is a need for a more efficient and affordable technique to visually inspect bridges. In fact, the use of drones has become more attractive to bridge owners, researchers and stakeholders due to their ability to gather critical information in less time and at a lower cost when compared to traditional inspection techniques.

Numerous research efforts [3–5] have been made to develop new techniques to monitor and inspect infrastructure. Drone technology has shed light on how to overcome time consuming, risky, and relatively expensive bridge inspection practices. For instance, Chan et al. [3] conducted a study on drone-based inspection compared to conventional inspection practices. To complete the study, several considerations were made concerning drone capabilities for bridge inspection, inspection requirements, cost-benefit analysis, and challenges of aerial platforms. It was concluded that drones have some advantages over conventional inspection practices including cost, time, reduced risk for inspectors, and inspection quality. A more in-depth study of structure inspection was conducted by Koch et al. [5]. During this study, the authors performed an analysis of large concrete structures, including bridge columns. To conduct the analysis, different inspection techniques, such as 3D surface reconstruction, were implemented to identify damage. The authors concluded that the drone-enabled inspection coupled with vision-based technology had potential to serve as a more economical and safe alternative to conventional inspection practices. It can be seen that drone technology has helped inspectors conduct visual assessment of infrastructure at a low cost and with less injury risk when compared to conventional inspection methods.

The primary goal of this research was to evaluate the capabilities of the drone technology as a supplemental bridge inspection tool to support legally mandated conventional bridge inspections. To that

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end, a selected bridge located near Keystone, South Dakota (SD) was inspected following state and federal regulations (i.e., SD Department of Transportation (SDDOT) and Federal Aviation Administration (FAA)). This paper is subdivided into five sections, including this section. The second section presents the selected drone and bridge for this study. The third section details the developed bridge inspection methodology, while the fourth section discusses the application of the methodology to the selected bridge in accordance with the state and federal regulations. The fifth section presents a comparison of results between drone-based and conventional bridge inspection. The final section provides conclusions and challenges during bridge inspection using drone technology.

## 2. Drone and bridge selection

This section is dedicated to the discussion of the drone and bridge selection; thus, the results of the selection process are presented in the following subsections.

### 2.1. Selected drone

The drone to conduct this study was chosen based upon different considerations including flight time, upward viewing camera, camera resolution, video resolution, and others. A number of researchers have utilized and studied a variety of drones to determine their proficiencies in terms of data gathering for bridge inspection. A total of 13 different drones were investigated (see Table 1) to efficiently select a suitable drone for bridge inspection. To efficiently select a drone, the following seven considerations were studied.

(1) **Flying time over 20 min**: longer inspection time allows for a more efficient and comprehensive bridge inspection as it minimizes interruptions to change the drone batteries;
(2) **Additional camera on top of drone**: the ability to observe directly under the deck permits a more detailed inspection;
(3) **Camera resolution with low illumination**: due to lack of illumination under the deck, the drone camera must be able to capture high-resolution images under low illumination. It can be noted that the illumination can be enhanced by additional flashlights either attached to the drone or located on the ground;
(4) **Video resolution**: aside from still images, the drone must be able to record high-definition videos to perform video-based inspection as needed;
(5) **Payload capacity**: payload is important as it allows the drone to carry additional attachments such as flashlights or cameras if needed;
(6) **Drone lights**: the drone Light-Emitting Diode (LED) lights included on some drones serve as a source of illumination and should be considered to provide extra illumination required for efficient damage observation underneath a bridge; and
(7) **Remote range**: some structures are located over water or are not accessible by inspectors. Therefore, a long-range remote control is required to inspect such structures.

Considering the aforementioned specifications, a total of four drones were deemed suitable for bridge inspection. The selected drones included the DJI Matrice 100, DJI S900, DJI Phantom 3 pro, and DJI Phantom 4. Among the suitable drones, the DJI Phantom 4 (see Fig. 1) was selected over the others due to its performance and versatility meeting the considered requirements at a reasonable cost. The intent of selecting an affordable drone was to provide a viable and cost-efficient alternative to current inspection practices that can be implemented by county-level administrations. Additional technology, which is Obstacle Avoidance (OA), allows the drone to avoid harm to both bridge and drone components along with persons and property. Another consideration was the ability to fly in manual mode to avoid Global Positioning System (GPS) signal under the bridge. It should be noted that drone technologies have rapidly grown in recent years; thus, their costs and features will change quickly over time.

### 2.2. Selected bridge

A glued-laminated girder bridge with a composite concrete deck was selected, as seen in Fig. 2. It can be noted that the bridge was selected based on the requirements from the project sponsor, the United States Department of Agriculture – Forest Products Laboratory (FPL). The bridge was located on US16 to US16A Highway, near the city of Keystone in Pennington County, SD. The bridge had three simply supported spans with four girders spaced at 2.3 m (7.5 ft.) on center (o.c.) and a clear width of 7.9 m (26 ft.). The bridge was horizontally curved at an estimated radius of 116.4 m (881.97 ft.) and is a 51.8 m (170 ft.) long with steel guardrails along the edges of the superstructure.

## 3. Bridge inspection methodology

Due to a lack of systematic damage identification and drone inspection procedures, a five-stage bridge inspection methodology that allowed for an efficient drone-enabled bridge inspection (see Fig. 3) was developed. The methodology was based on holistic information related to drone limitations, drone operation conditions, and data acquisition methodology. State and federal regulations were also considered. The methodology is detailed below:

Stage 1 is to complete the *Bridge Information Review*. Information, such as as-built plans, historical inspection reports, and other applicable documents, should be studied in this stage to ensure a complete inspection of the bridge structure. For instance, the review of the inspection reports allows a pilot to identify critical inspection locations (e.g., deck or girders) prior to the drone-enabled inspection. The information gained during this stage permits the pilot to develop flight strategies under limited bridge approachability conditions, identify current damage, and monitor or update critical damage such as concrete cracks on the target bridge.

Stage 2 is to perform a thorough *Site Risk Assessment* of the bridge's surrounding areas. This stage is intended to identify potential risks such as near trees or traffic lanes to safely proceed with the drone-enabled inspection. Other benefits of performing a site risk assessment prior to conducting the inspection include identification of safe landing/take off zones, safe bridge approaching areas, and pilot risk minimization. Additionally, state and federal regulations should be accounted for prior to establishing a flying strategy. Regulations vary from location to location; it is advised to confirm with DOTs and the FAA to identify potential applicable restrictions for the bridge location. Finally, to ensure pilot safety, traffic control mechanisms, such as warning signs near the pilot, should be implemented.

Stage 3 is to perform the *Drone Pre-flight Setup*. It is recommended, by both the FAA and drone manufacturers, to conduct a thorough inspection of the drone prior to the first flight of the day. Inspections of all the software and hardware including, but not limited to, propellers and rotors, battery levels of all instruments (e.g., a remote controller,