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Crack detection for bridge inspection utilizing UAV photogrammetry technique

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Abstract

With the expansion of transportation networks, road networks are also growing, resulting in an increased usage of bridges. Consequently, there will also be an increase in bridge deformations due to increased crossings. Inspecting bridges incurs significant maintenance costs. As a promising strategy to safeguard bridges, a bridge inspection method using UAVs with vision sensors is proposed. Crack identification methods on historic concrete bridges are investigated in this paper using a high-resolution vision sensor attached to a commercial UAV. In the preflight, a photorealistic 3D model based on point cloud is created before detecting cracks on the structural surface and calculating their thicknesses and lengths. A field experiment was performed to authenticate the suggested method, and the scientific findings demonstrated the efficacy of bridge inspection using UAVs in detecting and quantifying cracks in infrastructure.

1. Introduction

Continuous safety monitoring and maintenance of infrastructure such as bridges is essential. Effects such as fatigue, thermal expansion, contraction, and external loads degrade the performance of bridges over time. As bridges age, the number of bridges that need to be inspected increases, resulting in high maintenance costs. If spending on bridge maintenance is delayed, more costs will be required shortly (Kim et al., 2018). Therefore, many countries have established a maintenance plan for bridges. Since a crack directly reflects the condition of structures, it is considered one of the essential parameters for structural health monitoring (Fawzy et al., 2023). Traditional crack detection is performed by human visual inspection (Karataş et al. 2022a). This method has limitations as the performance is dependent on the experience of the inspector, time-consuming, and limited access areas (Unel et al. 2004).

Some approaches include the use of a charge-coupled device (CCD) camera, complementary metal-oxide-semiconductor (CMOS) image sensor, near-infrared (NIR), and hyperspectral camera. In most studies, image processing consists of the following steps: (1) image acquisition; (2) pre-processing techniques, which are efficient image processing methods; (3) image processing techniques such as binarisation and noise removal using a mask filter or morphological processing; and (4) crack measurement, which is a parameter estimation of the crack. Image binarisation methods have converted an RGB image into a binary one.

In recent years, bridge inspection based on unmanned aerial vehicles (UAVs) with high-resolution sensors has attracted much attention in many countries due to its safety and reliability. Using a UAV equipped with a camera to scan the bridge's surface and store the digital images taken during crack detection has many advantages. Due to its efficiency, speed, safety, and cost-effectiveness, local transportation departments are investigating and beginning to implement UAV-based bridge inspection technology (Kim et al., 2018). According to a report by the American Association of State Highway and Transportation Officials (AASHTO), 16 states use UAVs for bridge inspection. However, they roughly assess damage conditions without knowing their size and location (Dorafshan et al., 2017). A GPS-denied environment under a bridge reduces the stability of the UAV platform. Therefore, many flight planning methods using appearance image-based recognition (Han et al., 2015), simultaneous localization and mapping (SLAM)

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(Munguia et al., 2016), and real-time lidar odometry mapping (LOAM) have been proposed to reduce GPS errors. Other researchers have proposed and investigated a protocol for bridge inspection to overcome the challenges (Kim et al., 2018).

Crack detection methods based on machine learning and deep learning have recently been proposed (Cha et al., 2017). Features are obtained from crack images by training a convolutional neural network. The results of crack detection using these learning methods overcome the limitations of traditional image processing techniques such as drop and edge detection. To locate and visualize the detected crack, it should be supported by 3D models for a photorealistic Building Information Model (BIM) integrated with a UAV process. The advantages of photorealistic models generated by photogrammetry are easy visualization of structural elements and management of maintenance history (Feng et al., 2018). However, many bridges are without BIM, and deriving a new BIM requires much time and effort. Therefore, the UAV-based crack detection system is at an embryonic stage, which needs to solve many challenging problems in its practical applications. In addition, longer flight times and more stable flights are required for stable inspection. When approaching the bridge, it is essential to ensure that the field of view determines the pixel size of the image.

This paper investigates a crack identification method for an aging historic concrete bridge using a 3D model generated from images of a commercial UAV with a high-resolution camera. In such a study, the inspector can create a background model of a bridge without any information. He can also track the damage history by visualizing the cracks on the inspection map. The detailed process of this study is as follows. First, a point cloud-based bridge model was created in a preflight. Next, inspection images were captured by a high-resolution camera mounted on the UAV, and a 3D model was created to scan the structural elements. Finally, the cracks and crack size were estimated. In order to measure the cracks in the captured images, reference marks were previously placed on the structures and analyzed for accuracy.

2. Method

Continuous safety monitoring and maintenance of infrastructure such as bridges are essential issues. Effects such as fatigue, thermal expansion, contraction, and external loading degrade the performance of bridges over time (Fawzy et al., 2023). As bridges age, the number of bridges requiring inspection increases, resulting in high maintenance costs. If we delay spending on bridge maintenance, more costs will be required shortly. Therefore, many countries have established a maintenance plan for bridges (MacGregor et al., 1997). Since a crack is a direct reflection of the condition of a structure, it is considered one of the most essential parameters for structural health monitoring. Traditional crack detection is carried out by human visual inspection. This method has limitations, as the performance depends on the experience of the inspector, time consumption, and limited access areas.

Photogrammetry has been vital for centuries in understanding distant objects and the Earth's surface (Karataş et al. 2022b). Its uses have expanded over the years, and it is a method that uses powerful technologies constantly evolving in sectors such as construction, engineering, medicine, and many more (Karataş et al. 2022c). Photogrammetry can vary, but the general idea revolves around gathering information about an object from photographs (Alptekin and Yakar, 2021). Photographs are taken from different positions and angles to allow precise calculations to be made that help analysts gather the data they are looking for (Yakar, 2011). Typically, they use photo interpretation and geometric relationships to gather measurements. We can create maps and 3D models of real-world scenes with the data collected from photogrammetry (Şasi and Yakar, 2017; Kuşak et al. 2021).

The SfM algorithm is an algorithm that speeds up the photogrammetric process by developing software with technology (Alptekin and Yakar, 2020; Kanun et al. 2022). SfM is a photogrammetric algorithm that automatically solves a 3D target mesh with known scene geometry, camera positions, and orientation without pre-definition (Yakar and Doğan, 2017; Yakar et al. 2023). This algorithm allows self-calibration without pre-calibration (Kanun et al. 2021). Photogrammetric software using the SfM algorithm also uses a block balancing algorithm to optimize the projection errors between the image and the calculated point positions (Yılmaz et al. 2022).

Cracks can be broadly divided into two categories: structural cracks and non-structural cracks. Structural cracks are cracks caused by errors in design, construction, or overloading of the bridge member. On the other hand, non-structural cracks are caused by internal stresses in the bridge member that do not directly affect the structural behavior of the member. It can be referred to as 'direct damage' because the presence of the crack means that moisture reaches the steel reinforcement, corrodes the reinforcement, and eventually causes the bridge element to fail, but this process takes a long time to occur (Arvind, 2016; Chitte et al., 2018). In the study, Bentley Context Capture Centre Ultimate Edition was used to process the aerial images obtained by the UAV. The photogrammetric images were imported into the software. Context Capture was then aligned from the imported images. Finally, the software created a 3D model available in many formats. In this experiment, the 3MX 3D model format was chosen to open the production file obtained from the Context Capture Viewer, a tool for detecting cracks in the Context Capture Centre. Deep learning algorithms were then used to detect cracks in the generated 3D model.

3. Results

All 706 aerial photographs taken for the study were subjected to stabilization, and 696 were stabilized. Figure 1 shows the positional uncertainty of the anchor points, with a minimum uncertainty of 0.00015 m, a maximum uncertainty of 0.0039 m, and a median uncertainty of 0.0045 m. During block balancing, 230791 automatic connection points were created. The 3D model of the bridge used in the study is shown in Figure 1. A visualization of the detailed 3D model is shown in Figure 2.

Figure 1. 3D model of the bridge under study. The entire 3D model of the bridge (top), the part of the bridge studied in detail (bottom).

Figure 2. Detailed 3D model of the bridge

Figure 3. Detected cracks (north view)

Figure 4. Detected cracks (south view)

Cracks were detected using the crack detection algorithm in the artificial intelligence inspection tool provided by the context capture software for inspections of the 3D-modelled bridge. Figures 3, 4, and 5 show the visualizations of the detected cracks.

Figure 5. Detected cracks (east view)

4. Conclusion

Visual inspections for structural damage assessment and analysis are cumbersome, time-consuming, subjective, and difficult to document. Structural analysis from 3D models produced by photogrammetry aims to move towards automated damage assessment for monitoring an asset over its lifetime by developing a methodology to create a twin of individual structures using multiple images taken during inspections as input. It is recognized that this methodology will more efficiently document the information gathered during an inspection, increase objectivity, and reduce operational time. In addition, the 3D models produced are helpful for more detailed damage assessment activities such as mechanical analysis using numerical methods. The end products of the methodology include a 3D reconstructed geometry of a structure with cracks and their characterization. Advances in image capture hardware and artificial intelligence, including deep learning or machine learning and computer vision, make it possible to automate this pipeline using only RGB images. While existing damage assessment methods use techniques from these fields, they are limited to tasks that may require manual intervention, such as detecting damage or creating a 3D model for a specific asset. To do this, combining several state-of-the-art methods to build 3D building models and semantically segment and characterise cracks from images is necessary. The methodology proposed here requires multi-view images of the asset suitable for SfM as input. SfM processes the images, generating camera poses and a point cloud that is used to build a LOD3 model. Deep learning or machine learning trained to detect cracks processes the images used to build the 3D model. The cracks are then characterized by computing their kinematics using a 2D least squares registration algorithm. Finally, the damage information is mapped to the LOD3 model using SfM information to generate the desired DADT output. Looking at the overall results of the research, improvements to the current rapid damage assessment application are being developed. Following rapid assessment using this method, a more detailed analysis of damage characteristics may be required (e.g. crack depth estimation).

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