The CLGE Young Surveyors' Contest 2024
The Council of European Geodetic Surveyors (CLGE)
12th Edition of the Contest

CLGE Young Surveyors' Contest
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Title:
Validation of an end-to-end framework for UAS-assisted bridge inspections

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Level of study or work: PhD
(Bachelor thesis, master, PhD, research, project, etc.)

Information about you (and your team):
As the Geomatics Research Group in the Department of Civil Engineering, our work involves the acquisition, processing, management and visualisation of data to solve problems in the built environment. We focus on 3D modelling using photogrammetry and terrestrial laser scanning, computer vision and machine learning techniques, as well as linked data and augmented reality approaches.

My personal interest in the use of unmanned aerial systems (UAS) for bridge inspections started with my master's thesis topic in 2022, when I conducted a first evaluation of UAS close-range photogrammetry of the Filstalbrücke, one of the highest bridges in Germany and part of Stuttgart 21, a major railway and urban development project. This experience led me to pursue a PhD in Geomatics to fully explore the potential of this technology.

Area of interest

(Identifying the problem, explain why it is important and the current relevance of the topic, up to 250 words)

Bridge inspections are vital but challenging. Traditional methods typically involve rappelling or the use of inspection trucks to access the underside of bridges. These conventional approaches pose significant risks to inspectors, disrupt traffic and are time consuming. In addition, the data collected during such inspections is often subjective and incomplete. For example, structural defects, such as cracks, may only be partially measured and inadequately documented, making consistent tracking and analysis difficult.

The use of UAS offers a promising alternative, providing safe and rapid access to hard-to-reach areas and capturing high-resolution image and video data. However, despite the potential of machine learning to automate damage detection and facilitate detailed comparisons over time, full utilisation of UAS technology requires substantial research in several specific areas. These include optimising flight paths, ensuring reliable 3D reconstruction, developing suitable object detection models for bridge damages, and implementing effective data management strategies. To fully leverage this technology, it is essential to develop an integrated system that covers every step from data collection to the final presentation of data to bridge inspectors.

Given the complexity involved and the critical need for improved inspection techniques as global bridge infrastructure ages, UAS technology has become a key research area over the past decade. The integration of advanced computer vision and machine learning techniques could transform bridge inspection methodologies, improving both the safety of inspectors and longevity of infrastructure. This research aims to contribute to the field by exploring and developing these emerging technologies.

Approach to the problem

(Describe your methodology or technology and how it will solve the problem you identified, up to 300 words)

Previous studies [1] focus on manual flights, which do not ensure constant distance and accurate viewing angles, resulting in inaccurate data. In addition, manual flights allow for human error, which compromises safety. Our approach utilizes computed 3D flight paths based on the trajectory of the bridge, which can be executed automatically. We incorporate safety offsets and designate no-fly zones near obstacles, such as trees and power lines. This automation ensures that the drone pilot focuses solely on capturing optimal viewing angles, enhancing data quality while adhering to European drone regulations.

Typically, creating a 3D model of a bridge involves setting up labour-intensive ground control points (GCPs). We simplify this process by using the Real-Time Kinematic (RTK) module on the UAS to directly georeference the model. By leveraging the Agisoft Metashape software development kit (SDK) [2], we streamline the transformation of captured images into a textured, georeferenced 3D model and automate the export of camera positions. We verify the accuracy of our results by conducting cloud-to-cloud (C2C) comparison with terrestrial laser scans (TLS).

We develop a specialized object detection model using the YOLOv8 architecture [3] to identify common types of bridge damage. Existing public datasets and models often do not align with the high-resolution imagery typical in bridge inspections. Since fully supervised image annotation is time intensive, we developed an annotation tool that pre-labels data using a preliminary detection model, which significantly reduces the time spent annotating images.

In the last step, detected damages are mapped onto the 3D model to categorize and group damage candidates based on specific locations and types. We propose a linked data approach to manage the extracted data, which facilitates the filtering of false positive predictions. The final validated data is then presented to bridge inspectors remotely, enabling them to make informed decisions without onsite visits.

Results, conclusions and next steps

(Present your results and conclusions of your study, up to 250 words)

In this study, we used the DJI Mavic 3 Enterprise to validate our methodology on a 150 m canal bridge, covering flight planning to data presentation. We computed several flight routes, starting with a deck flight for reliable RTK data and image overlap with underdeck flights. Due to unreliable RTK data from the underdeck flights, we used vertical flights (**Fig. 1**) at each section's start and end for alignment. The data acquisition, handling difficult scenarios like flying over trees but below powerlines, took 2 hours. Vertical connection flights ensured successful alignment of all 2,500 images with a 2.2 cm error. The final 3D model, computed in 14 hours, included a high-resolution texture map for assessing structural damage (**Fig. 2**). Besides needing less time compared to TLS, which required 4.5 hours on-site, this method provided better coverage, especially between I-girders. The C2C analysis showed less than 4.5 cm deviation in 90% of data points within the photogrammetric point cloud (**Fig. 3**), indicating the effectiveness and accuracy of UAS photogrammetry.

The full study includes the semi-supervised training process of 25 GB of image data from a decade of bridge inspections, including fine-tuning and Sliding Aided Hyper Inference (SAHI) during inference for our exposed rebar detection model (**Fig. 4**). Detected damages were accurately mapped onto 3D models, filtering out false predictions based on location relevance, frequency, and size thresholds. Lastly, we demonstrate a graphical user interface, which allows inspectors to make final decisions and quickly assess the computed damage candidates for reports (**Fig. 5**).

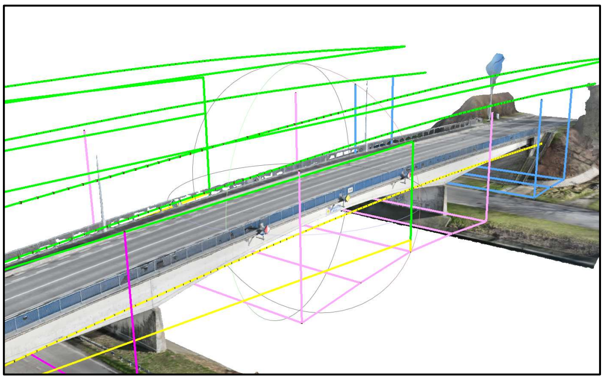

Figure 1: Computed flight routes.
The proposed vertical connection flights ensure sufficient overlap between the underdeck images with the RTK flight (green).

Figure 2: Resulting photogrammetric 3D model.
The high resolution of 6 x 8k texture maps allow for identification of complex damages such as e.g., exposed bars (blue), water leakage (orange) and graffiti (yellow).

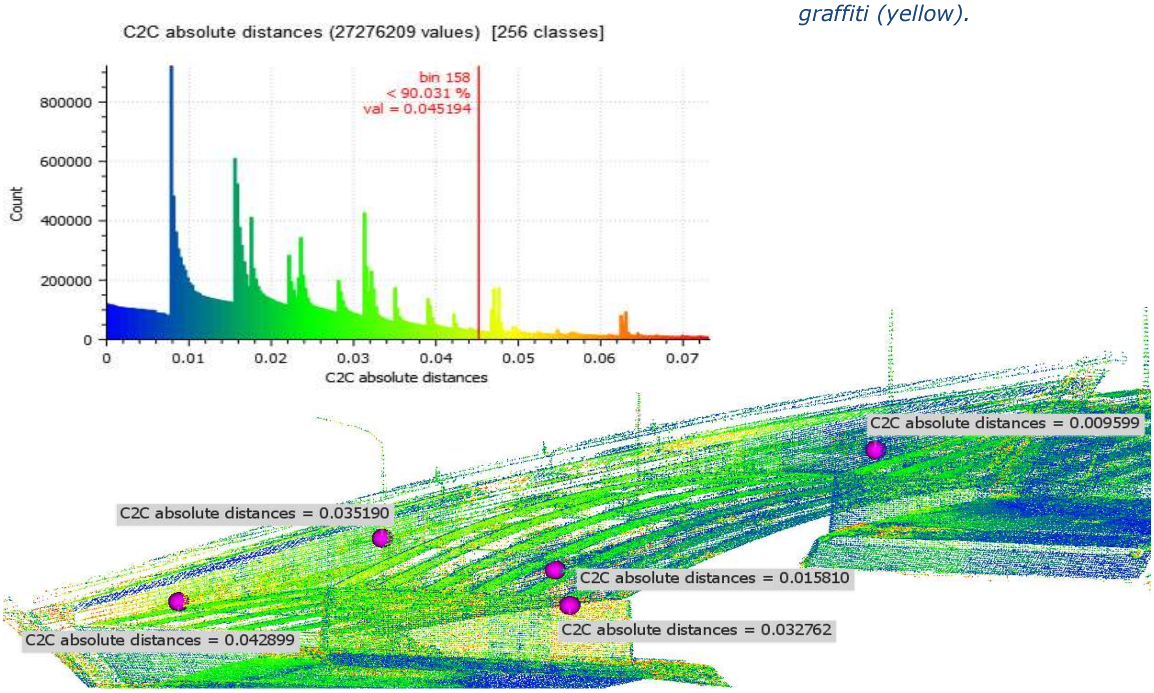

Figure 3: Cloud-to-Cloud comparison between the photogrammetric and the TLS point cloud.
The histogram (top) presents that less than 90% of the photogrammetric point cloud deviates more than 4.5 cm from the TLS point cloud data. A detailed presentation of the C2C comparison shows the full bridge from underneath with punctual measurements (below).

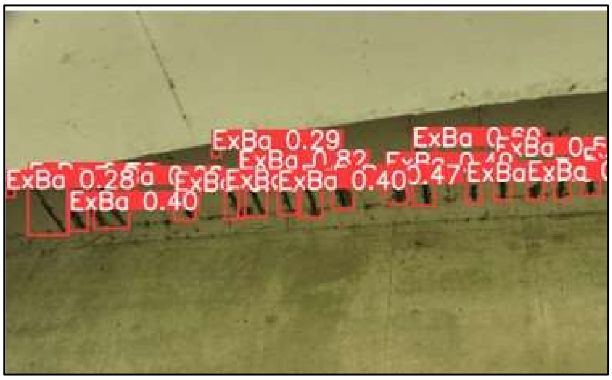

Figure 4: Damage detection model results.
Using SAHI during Inference, we were able to detect even small, exposed rebars between I-girders.

Figure 5: Visualizing final damage candidates in reporting interface. *Detected damages from several images are grouped by location and damage class. Viewing a damage from different viewing angles facilitates the final evaluation of bridge inspectors off-site.*

References

(Additional information, publications, or links, up to 200 words, optional)

[1] S. Chen, X. Zeng, D. F. Laefer, L. Truong-Hong, and E. Mangina, "Flight Path Setting and Data Quality Assessments for Unmanned-Aerial-Vehicle-Based Photogrammetric Bridge Deck Documentation," Sensors, vol. 23, no. 16, article 7159, Aug. 2023. Doi: https://doi.org/10.3390/s23167159

[2] Agisoft Metashape, version 2.0. [Software].

[3] G. Jocher, A. Chaurasia, and J. Qiu, "Ultralytics YOLO," version 8.0.0, Ultralytics, 2023. [Software]. Available: https://github.com/ultralytics/ultralytics

For further information, a rendered model preview of the work can be viewed at: https://sketchfab.com/3d-models/3d-bridge-model-of-lovendegembrug-83a71b2937104f21ba978cb62855ad2d

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