Improving Infrastructure Monitoring: UAV-Based Photogrammetry for Crack Pattern Inspection

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Abstract

Infrastructure degradation, including cracking and occlusions, poses significant risks to structural integrity, demanding efficient monitoring and interventions. Geomatic techniques, especially UAV photogrammetry, offer promising avenues for crack pattern inspection. This study aims to develop a rapid and replicable investigation methodology for crack pattern inspection applicable across various materials and structures. Initially focusing on reinforced concrete, the research aims to optimize the investigation process, favoring automatic or semi-automatic approaches. Exploiting UAV-based photogrammetry, detailed and panoramic images facilitate crack identification and structural health assessment. The methodology involves photogrammetric reconstruction of specimens, orthophoto extraction, and filtering for edge enhancement. Object-Based Image Analysis (OBIA) classification is utilized for automatic crack extraction. The study evaluates the effectiveness of specific filters, including Enhanced Frost and Median, in refining crack detection. While promising results are obtained, further refinement and testing are warranted. The proposed methodology holds the potential for creating a rapid, effective, and easily replicable infrastructure monitoring system, contributing to safety and sustainability.

1. INTRODUCTION

Infrastructure plays a fundamental role in supporting human activities, yet it is often subjected to various degradation factors that can compromise its structural integrity and functionality over time. Among the primary risks associated with infrastructure, degradation, cracking, and possible occlusions represent significant issues that necessitate careful monitoring and timely interventions [1-2]. This study focuses on the automated extraction and analysis of cracks in concrete specimens using UAV-based photogrammetry and Object-Based Image Analysis (OBIA) [3]. The objective is to explore the application of convolution filters—Median, Enhanced Lee, and Enhanced Frost [4]—in enhancing crack detection through OBIA. The research aims to evaluate the effectiveness of these filters in improving feature delineation and classification accuracy for structural monitoring, with the goal of establishing a reliable and automated methodology for continuous infrastructure assessment.

2. MATERIALS AND METHODS

This study uses orthophotos derived from UAV-based photogrammetry to assess cracks in a concrete specimen. UAVs equipped with high-resolution cameras were used to capture images of the specimen (Fig. 1-2), and Structure-from-Motion (SfM) algorithms were applied to generate orthophotos. These were carefully processed to highlight cracks and other structural features. The region of interest (ROI) (Fig.3) in the orthophotos, where the cracks were expected to be located, underwent pre-processing using convolutional filters to enhance the crack edges and reduce noise in the images. Three types of convolution filters were selected for this study: the Median filter, the Enhanced Lee filter, and the Enhanced Frost filter. The Median filter is commonly used for noise reduction, providing a smoothing effect that reduces outlier values without blurring the image too much. The Enhanced Lee filter, which is often used for reducing speckle noise in remote sensing images, enhances contrast and sharpens edges. The Enhanced Frost filter, on the other hand, is designed to improve edge detection and emphasize features such as cracks by preserving fine details while reducing other unwanted image noise. Once the filters were applied, OBIA was performed to classify the cracks in both the untreated and filter-treated images (Fig.4-5-6-7). OBIA is a technique that groups pixels into meaningful objects or segments based on their spectral properties and spatial relationships, making it particularly useful for distinguishing cracks from other features in the image [5-6]. For validation, the study used Ground Truth (GT) data, which was obtained through manual visual inspections of the concrete specimen. These inspections identified the cracks in the concrete, which were then used as a reference for assessing the performance of the crack detection and classification methods. To quantitatively evaluate the effectiveness of the OBIA classification, the Jaccard similarity coefficient was applied (1) [7-8].

$$Jaccard\ Index = \frac{|A \cap B|}{|A \cup B|} \tag{1}$$

where A = It is the GT's cracking class
B = It is the cracking class to compare

This metric compares the overlap between the classified cracks and the GT data, providing a measure of the accuracy of the classification. Additionally, the classification performance, in terms of crack detection, was analyzed for each ROI, comparing the results from the untreated ROIs and those processed with the convolution filters. This analysis helped to evaluate the performance of the different filters in terms of improving the accuracy of crack detection and classification. These metrics are essential for understanding the impact of the pre-processing filters on the crack detection process, and for determining the optimal method for accurately identifying cracks in UAV-based orthophotos.

3.RESULTS AND DISCUSSION

The application of the filters demonstrated clear improvements in crack detection. The Median and Enhanced Frost filters yielded better results compared to the Enhanced Lee filter and the untreated orthophoto. The Enhanced Frost filter, in particular, consistently outperformed the other filters in terms of crack identification, despite the presence of noise and occlusions caused by transducers. The Jaccard similarity coefficient indicated a significant improvement in crack detection with the application of filters, particularly the Enhanced Frost filter (Table 1). The filters enhanced crack identification, with the Frost filter detecting cracks more effectively, even those as small as 3 mm. However, cracks smaller than 2 mm were challenging to detect and may require further refinement in the methodology. Despite the promising results, some cracks were missed or detected inaccurately due to interference and occlusions in the data, particularly from transducers and shadows. The findings underscore the potential of UAV-based photogrammetry and OBIA for non-invasive, automated crack detection, offering a significant advantage over traditional inspection methods that are time-consuming and involve greater safety risks. The methodology was shown to be effective for rapid crack analysis, and the integration of OBIA allowed for improved differentiation between cracks and noise compared to basic edge detection techniques. However, the study also highlighted areas for further improvement, particularly in optimizing algorithms and extending the methodology to different types of materials and structural conditions. Future work will focus on refining the detection algorithm, testing additional filters, and incorporating advanced Machine Learning techniques to enhance the crack detection process. These advancements will help make the methodology more adaptable and applicable to a broader range of infrastructure types, contributing to better structural monitoring and maintenance practices.

Figure 1. From top to botton image and technical specifications of the UAV and Zenmuse X5S used in this work.

Figure 2. Reinforced concrete specimen used for testing

Figure 3. Orthomosaic of the chosen ROI at the node of the reinforced concrete specimen used following the compression test, characterized by cracking (processed with Agisoft Metashape software).

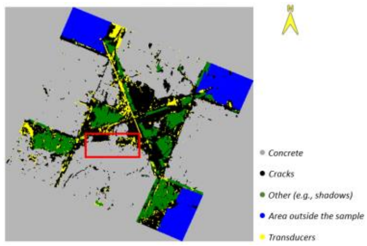

Figure 4. OBIA classification on the unprocessed orthophoto. The red box represents a sample area where a crack can be identified.

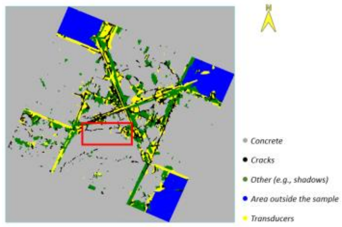

Figure 5. OBIA classification on the orthophoto with *Median* filter. The red box represents a sample area where the improvement in crack identification can be observed. The crack is highlighted within the red box, demonstrating how the application of the *Median* filter has enhanced the ability to identify cracks in the ROI.

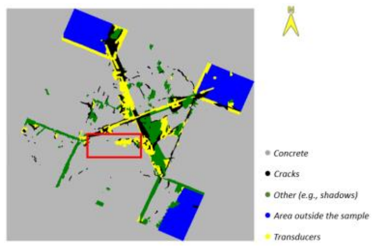

Figure 6. OBIA classification on the orthophoto with *Enhanced Lee* filter. The red box represents the same sample area considered where the identification of cracks can be observed with the application of the *Enhanced Lee* filter.

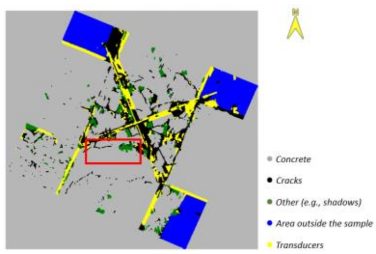

Figure 7. OBIA classification on the orthophoto with *Enhanced Frost* filter. The red box represents the same sample area considered where the identification of cracks can be observed with the application of the *Enhanced Frost* filter.

TABLE 1. PERCENTAGE OF CRACKS OBTAINED AS A RESULT OF THE JACCARD SIMILARITY COEFFICIENT IDENTIFIED IN EACH CLASSIFICATION

	GT	***ROI***	***Enhanced LEE***	***Enhanced FROST***	***MEDIAN***
Number of cracks	65	24	32	61	52
Match after Jaccard Index		37%	49%	94%	80%

REFERENCES

[1] Detchev, I., Habib, A., & El-Badry, M. (2012, March). Extraction of cracks from concrete beam images. In Proceedings of ASPRS 2012 annual conference, Sacramento.

[2] Mishra, M., Lourenço, P. B., & Ramana, G. V. (2022). Structural health monitoring of civil engineering structures by using the internet of things: A review. Journal of Building Engineering, 48, 103954. https://doi.org/10.1016/j.jobe.2021.103954

[3] Zollini, S., Alicandro, M., Dominici, D., Quaresima, R., & Giallonardo, M. (2020). UAV photogrammetry for concrete bridge inspection using object-based image analysis (OBIA). Remote Sensing, 12(19), 3180, https://doi.org/10.3390/rs12193180.

[4] Lopes, A., R. Touzi, and E. Nezry. "Adaptive Speckle Filters and Scene Heterogeneity." IEEE Transactions on Geoscience and Remote Sensing 28, No. 6 (1990): 992-1000 doi: 10.1109/36.62623.

[5] Fernandez Galarreta, J., Kerle, N., and Gerke, M.: UAV-based urban structural damage assessment using object-based image analysis and semantic reasoning, Nat. Hazards Earth Syst. Sci., 15, 1087–1101, https://doi.org/10.5194/nhess-15-1087-2015, 2015.

[6] Rau, J. Y., Hsiao, K. W., Jhan, J. P., Wang, S. H., Fang, W. C., and Wang, J. L.: BRIDGE CRACK DETECTION USING MULTI-ROTARY UAV AND OBJECT-BASE IMAGE ANALYSIS, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W6, 311–318, https://doi.org/10.5194/isprs-archives-XLII-2-W6-311-2017, 2017.

[7] Jaccard, P. (1901). Étude comparative de la distribution florale dans une portion des Alpes et des Jura. Bulletin de la Société Vaudoise des Sciences Naturelles, 37, 547-579.

[8] Jaccard, P. (1912). The Distribution of the Flora of the Alpine Zone. New Phytologist, 11, 37-50, http://dx.doi.org/10.1111/j.1469-8137.1912.tb05611.x.