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Damage Detection and Monitoring of a Concrete Structure Using 3D Laser Scanning †

Manik Das Adhikari [1], Tae-Hwan Kim [2], Sang-Guk Yum [1,*] and Joon-Yeong Kim [3]

[1] Department of Civil Engineering, Gangneung-Wonju National University, Gangneung 25457, Republic of Korea; rsgis.manik@gmail.com
[2] Department of Security Service, Yongin University, Yongin 17092, Republic of Korea; twehwan@empas.com
[3] Department of R&D Lab, SQ Engineering Co. Ltd., Sonpa-gu, Seoul 05818, Republic of Korea; kimjoonyeong@sqeng.co.kr
* Correspondence: skyeom0401@gwnu.ac.kr

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Abstract: Surface damage detection, geometry measurement and monitoring are important for assessing the condition and risk of concrete structures. Therefore, to effectively assess the damage to a concrete structure, a 3D laser scanner accurately estimates the damage within a short timeframe and with less cost than the traditional inspection approaches. This study presents a framework for automated surface damage detection and structural health monitoring of a concrete structure using a X7 laser scanner (Trimble, Westminster, CO, USA). The methodology includes the use of 3D laser scanning technology to capture the 3D geometry of the concrete structure, followed by a detailed analysis of the data to identify any areas of damage or crack. The isodata and object-based image analysis (OBIA) techniques were applied to a 2D image generated from 3D cloud points. Overall accuracy (>89.6) and kappa statistics (>0.83) of both classification techniques exhibit good agreement between the classified and reference image. The OBIA technique was shown to be more effective in detecting minor cracks (<5 mm) and damage on a concrete structure. It was observed that the proposed approach is effective at identifying and monitoring the structural health of a concrete structure. The ability to continuously monitor the structure in this manner allows for early detection of damage and can aid in the maintenance and repair of the structure. Furthermore, this approach can robustly perform structural health monitoring and damage estimation.

Keywords: laser scanning; point clouds; surface damage detection; image classification; monitoring; damage quantification

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1. Introduction

Concrete structures are widely used in various applications, such as buildings, bridges, dams and highways. Over time, these structures may experience various types of damage, including cracking, spalling, and deformation, which can compromise their structural integrity and pose a risk to public safety. Therefore, the monitoring and maintenance of civil structures are critical to ensure the safety and long-term sustainability of infrastructure. Consequently, this study aims to develop an efficient and accurate method for detecting and monitoring damage in concrete structures. In recent years, 3D laser scanning technology has gained attention as a powerful tool for damage detection and monitoring of concrete structures [1–3]. This technology uses laser beams to capture the 3D geometry of the structure, creating a point cloud that can be processed and analyzed to detect any areas of damage or deformation [4]. Compared to traditional methods, such as visual inspection and manual measurements, 3D laser scanning offers several advantages, including high accuracy, precision, and efficiency [5]. Numerous researchers [2,3,6–10] used 3D laser scanning data to detect and monitor concrete structures' damages. Yoon et al. [6] developed an algorithm for detecting cracks in concrete tunnels based on 3D laser scanning data. Rabah et al. [8] used terrestrial laser scan data for automatic concrete crack detection and mapping. Cho et al. [2] used 3D laser scanning to monitor the deformation and cracks of a concrete structure. Another interesting application of 3D laser scanning for concrete structure monitoring was demonstrated by Ge et al. [10]. Therefore, it was observed that 3D laser scanning technology has proven to be a valuable tool for damage detection and monitoring of concrete structures.

The study aims to develop an efficient and accurate method for detecting and monitoring damage in concrete structures, contributing to developing more reliable and resilient infrastructure. Subsequently, we present a comprehensive study on the damage detection and monitoring of a concrete structure using 3D laser scanning technology. This technique transforms the point cloud into a 3D image, and the last is converted into a 2D intensity image for image processing. The intensity image is analyzed using isodata (unsupervised) and object-based image analysis (OBIA) techniques, and the damaged area is detected.

2. Materials and Methods

This study presents a framework for automated surface damage detection and structural health monitoring of a concrete structure using a 3D laser scanner. The proposed method comprises the following steps: (a) scanning the concrete structure to create a detailed point cloud; (b) pre-processing and analyzing the point cloud data to identify potential damage states such as cracks, voids, and deformations; and (c) evaluating the precision of the identified damage surfaces. The workflow of 3D scanner-based structural health monitoring of concrete structures is depicted in Figure 1.

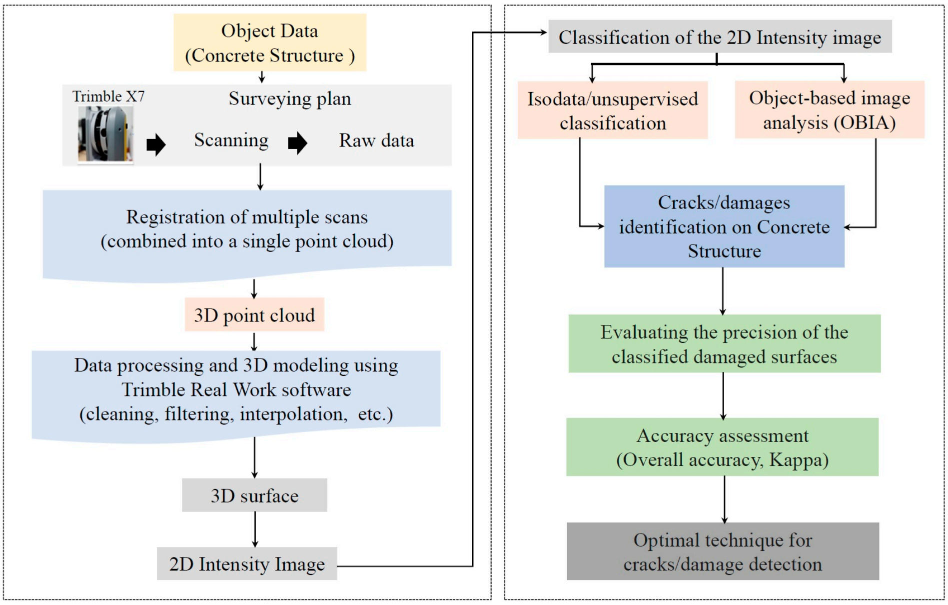

Figure 1. The workflow of 3D laser scanner-based structural health monitoring (data acquisition, processing, creation of 3D model, and damage detection) of a concrete structure.

We used a Trimble X7 laser scanner to collect the high-density 3D point cloud of a concrete structure. This instrument has a range of 0.6 m to 80 m, a precision of 2 mm and a maximum scanning speed of 500 kHz. In the present study, Trimble RealWorks 12.1 software (Trimble, Westminster, CO, USA)was used to pre-process point cloud data. The 3D surface model was then converted to the 2D intensity image for image processing purposes. The isodata and OBIA algorithm was used to classify the 2D intensity image [7,11]. The image classification was done using ERDAS Imagine 8.5 (ERDAS Inc., Norcross, GA., USA) and SAGA GIS 7.8.2 [12] software. Thereafter, the accuracy and kappa statistic were measured to evaluate the performance of classification models. These techniques are frequently used to determine a classification model's effectiveness [7]. The overall accuracy is a standard statistic that computes the proportion of correctly identified cases in relation to the total number of instances. On the other hand, the kappa statistic is a more sophisticated measure that considers the agreement between the actual observations and the predicted classifications while also considering the possibility of chance agreement [13]. Generally, a high overall accuracy and a high kappa statistic indicate good performance of the classification model and vice-versa. In the present study, we calculated the accuracy statistics based on the classified (i.e., isodata and OBIA) and reference image. The high-resolution RGB image collected by the same scanner was used as reference data. Subsequently, 550 random samples were collected from different parts of the high-resolution RGB image in order to compute the accuracy statistics for both classification models. The random samples contain information about the actual conditions of the concrete surface in the area covered by the classified image. After that, we developed a confusion matrix based on the classified and reference data in order to assess the overall accuracy and kappa statistic [14].

3. Results and Discussion

The study involved the use of a X7 3D laser scanner (Trimble, Westminster, CO, USA) to capture the 3D surface geometry of the concrete structure. The filtered cloud point was used to determine the region of interest, and the 3D surface was used to create the 2D intensity image. After that, the isodata and OBIA algorithm was used to classify the 2D intensity image into intact, damaged and cracked walls. Figure 2 depicts the classified image generated from 2D intensity data. It was observed that both classification techniques provide accurate and detailed information about the structure's condition, which can be used for further analysis and repair. To understand the precision of both classification techniques, we calculated the overall accuracy and kappa statistics based on the classified and reference image. The classification showed that the overall accuracy of the isodata and OBIA technique is 89.61% and 90.74%, respectively (Table 1). The calculated kappa value for the isodata and OBIA technique is 0.835 and 0.858, respectively, and exhibits good agreement of the classified and reference RGB images. The OBIA technique was shown to be more effective in detecting minor cracks (<5 mm) and damage on a concrete structure. The findings show that the Trimble X7 laser scanner has a high accuracy in capturing 3D cloud points, which is the sole cause of high accuracy in detecting the damage on the concrete wall. The use of 3D laser scanning can also reduce the time and cost required for inspection, as it eliminates the need for manual measurement.

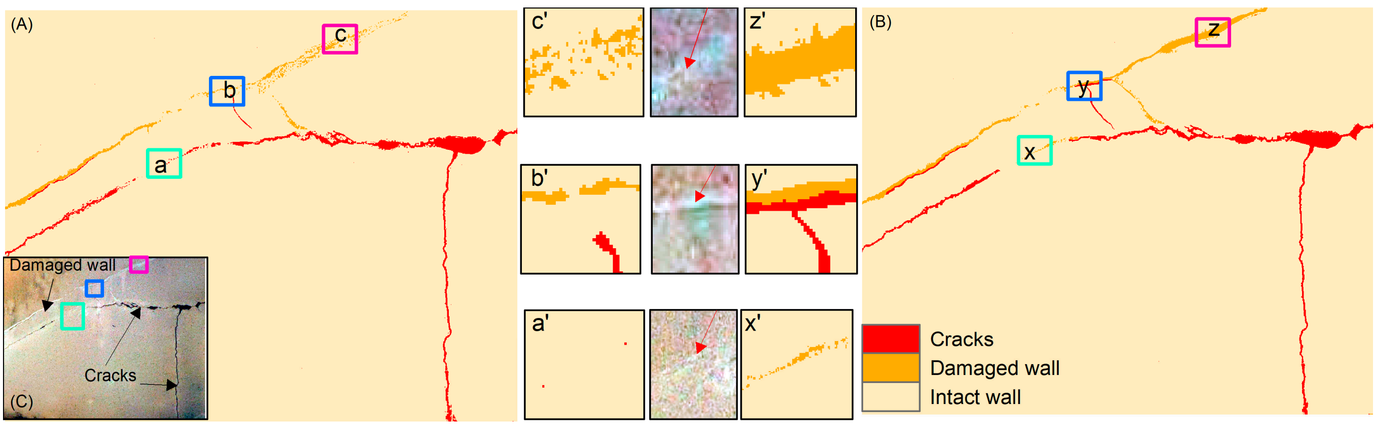

Figure 2. Cracks/damage detection of a concrete structure based on the (**A**) Isodata and (**B**) OBIA technique, whereas (**C**) represents the high-resolution RGB image. The zoom boxes represented by lowercase letters exhibit the detailed classification comparison of both techniques.

Table 1. Accuracy statistics of different classification techniques.

Classification Techniques		Cracks	Intact Wall	Damage Wall		Cracks	Intact Wall	Damage Wall	Overall Accuracy	Kappa
isodata	Producer's Accuracy	83.03	96.98	56.16	User's Accuracy	84.54	92.07	78.84	89.61	0.835
OBIA		90.69	97.63	45.31		87.31	92.60	80.55	90.74	0.858

4. Conclusions

The 3D laser scanning technology has been successfully used to detect and monitor damage in concrete structures. This research illustrated the step used to assess the efficiency of the Trimble X7 laser scanner in detecting cracks and damage on the concrete structure. The present methodology combined 3D cloud points and an image classification method to detect damage on the concrete structure. It was noted that the OBIA and isodata approaches show good agreement between the classified and reference images in terms of overall accuracy (>89.6) and kappa statistics (>0.83). Therefore, the proposed methodology can be suitable for monitoring an infrastructure's health. Furthermore, 3D laser scanning for damage detection and monitoring has several advantages over traditional inspection methods. This technique is non-destructive, meaning that it does not damage the inspected structure. This is particularly important in cases where the structure is still in use and cannot be shut down for inspection. In addition, the present technique provides accurate and detailed information about the structure's condition, which can be used for further investigation and restoration purposes. These findings have important implications for the field of civil engineering and suggest that 3D laser scanning will continue to play an important role in detecting and evaluating surface damage in concrete structures.

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References

1. Erkal, B.G.; Hajjar, J.F. Laser-based surface damage detection and quantification using predicted surface properties. *Autom. Constr.* **2017**, *83*, 285–302. [CrossRef]
2. Cho, S.; Park, S.; Cha, G.; Oh, T. Development of image processing for crack detection on concrete structures through terrestrial laser scanning associated with the octree structure. *Appl. Sci.* **2018**, *8*, 2373. [CrossRef]
3. Tzortzinis, G.; Ai, C.; Breña, S.F.; Gerasimidis, S. Using 3D laser scanning for estimating the capacity of corroded steel bridge girders: Experiments, computations and analytical solutions. *Eng. Struct.* **2022**, *265*, 114407. [CrossRef]
4. Wu, C.; Yuan, Y.; Tang, Y.; Tian, B. Application of terrestrial laser scanning (TLS) in the architecture, engineering and construction (AEC) industry. *Sensors* **2021**, *22*, 265. [CrossRef]
5. Mishra, M.; Lourenço, P.B.; Ramana, G.V. Structural health monitoring of civil engineering structures by using the internet of things: A review. *J. Build. Eng.* **2022**, *48*, 103954. [CrossRef]
6. Yoon, J.S.; Sagong, M.; Lee, J.S.; Lee, K.S. Feature extraction of a concrete tunnel liner from 3D laser scanning data. *NDT E Int.* **2009**, *42*, 97–105. [CrossRef]

7. Armesto-González, J.; Riveiro-Rodríguez, B.; González-Aguilera, D.; Rivas-Brea, M.T. Terrestrial laser scanning intensity data applied to damage detection for historical buildings. *J. Archaeol. Sci.* **2010**, *37*, 3037–3047. [CrossRef]
8. Rabah, M.; Elhattab, A.; Fayad, A. Automatic concrete cracks detection and mapping of terrestrial laser scan data. *NRIAG J. Astron. Geophys.* **2013**, *2*, 250–255. [CrossRef]
9. Valença, J.; Puente, I.; Júlio, E.N.B.S.; González-Jorge, H.; Arias-Sánchez, P. Assessment of cracks on concrete bridges using image processing supported by laser scanning survey. *Constr. Build. Mater.* **2017**, *146*, 668–678. [CrossRef]
10. Ge, Y.; Liu, J.; Zhang, X.; Tang, H.; Xia, X. Automated Detection and Characterization of Cracks on Concrete Using Laser Scanning. *J. Infrastruct. Syst.* **2023**, *29*, 04023005. [CrossRef]
11. Gui, R.; Xu, X.; Zhang, D.; Pu, F. Object-based crack detection and attribute extraction from laser-scanning 3D profile data. *IEEE Access* **2019**, *7*, 172728–172743. [CrossRef]
12. Conrad, O.; Bechtel, B.; Bock, M.; Dietrich, H.; Fischer, E.; Gerlitz, L.; Wehberg, J.; Wichmann, V.; Böhner, J. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. *Geosci. Model Dev.* **2015**, *8*, 1991–2007. [CrossRef]
13. Landis, J.R.; Koch, G.G. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics* **1977**, *33*, 363–374. [CrossRef] [PubMed]
14. Story, M.; Congalton, R.G. Accuracy assessment: A user's perspective. *Photogramm. Eng. Remote Sens.* **1986**, *52*, 397–399.