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Automated Concrete Crack Detection Using Digital Image Processing and Artificial Intelligence

Jawahar Lal
M. Tech. in Structural Engineering, Sat Kabir Institute of Technology and Management, Haryana.

Heera Lal
A.P Civil Department, Sat Kabir Institute of Technology and Management, Haryana.

ABSTRACT

Concrete structures are prone to cracks due to loading, shrinkage, corrosion, thermal stress, seismic effects, and environmental deterioration. Manual crack inspection is often time-consuming, subjective, and inconsistent. This study focuses on automated concrete crack detection using digital image processing and artificial intelligence techniques. Methods such as image enhancement, edge detection, segmentation, feature extraction, convolutional neural networks, U-Net, YOLO-based models, UAV imaging, and digital image correlation improve crack identification, classification, and damage assessment. These intelligent systems support faster, safer, and more accurate structural health monitoring, helping engineers reduce maintenance costs and improve the durability and safety of civil infrastructure.

Keywords: *Concrete Cracks, Digital Image Processing, Artificial Intelligence, Structural Health Monitoring, Crack Detection.*

I. INTRODUCTION

Concrete has remained one of the most widely used construction materials in civil engineering due to its strength, durability, and adaptability in various structural applications such as buildings, bridges, dams, and industrial facilities. However, despite its widespread use, concrete structures are inherently vulnerable to deterioration over time due to environmental exposure, mechanical loading, material aging, and internal microstructural weaknesses. One of the most critical indicators of structural degradation in concrete is crack formation, which often serves as an early warning sign of progressive damage and potential structural failure. Cracks may develop due to shrinkage, thermal stresses, corrosion of reinforcement, excessive loading, or seismic activities, and their presence significantly affects both the aesthetic and structural integrity of infrastructure systems. Zarefa and Mirzaei (2026) emphasized that concrete structures are highly susceptible to degradation caused by internal flaws and external stresses, where crack development plays a decisive role in reducing durability and load-bearing capacity. Traditionally, crack inspection has been performed manually by trained engineers through visual observation and simple measurement tools; however, such approaches are time-consuming, subjective, and often inconsistent in identifying crack severity and patterns. Shahrokhinasab et al. (2020) further noted that conventional inspection methods rely heavily on human judgment, which introduces errors and variability in assessment outcomes. As infrastructure systems continue to age globally, the need for more reliable, objective, and automated crack detection methods has become increasingly critical for ensuring structural safety and reducing maintenance costs.

In recent years, advancements in digital image processing and artificial intelligence have significantly transformed the field of structural health monitoring by enabling automated detection, classification, and quantification of cracks in concrete structures. Digital image processing techniques utilize image enhancement, edge detection, segmentation, and feature extraction algorithms to identify cracks from captured images of structural surfaces. Techniques such as Otsu thresholding and Canny edge detection have been widely applied to isolate crack regions from background noise, improving the accuracy of detection in complex environments. Zarefa and Mirzaei (2026) proposed a hybrid methodology that integrated classical image processing techniques with manual evaluation, demonstrating improved consistency in crack identification across different structural conditions. Similarly, Han et al. (2022) demonstrated that combining convolutional neural networks with image processing techniques achieved high accuracy in crack detection, reporting classification accuracy of 98.26%, thereby highlighting the potential of hybrid approaches in improving detection reliability. The integration of deep learning models, particularly U-Net architectures, has further enhanced the capability of automated systems to perform pixel-level segmentation of cracks, enabling more precise damage assessment. Hacıefendioğlu and Demir (2026) applied U-Net-based deep learning models for post-earthquake damage assessment using data from the Kahramanmaraş earthquake and found that such models significantly outperformed traditional visual inspection methods, achieving an IoU score of 0.737 for crack detection. Moreover, ensemble-based deep learning approaches such as YOLOv8 have been developed to improve real-time crack detection performance, offering high precision and reduced inference time, as demonstrated by Sohaib, Jamil, and Kim (2024). These advancements indicate a clear shift from manual inspection toward intelligent, data-driven systems capable of supporting rapid infrastructure evaluation.

The integration of digital image processing with emerging technologies such as unmanned aerial vehicles (UAVs), 3D modeling, and digital image correlation (DIC) has further expanded the scope of automated structural damage assessment. UAV-based inspection systems enable large-scale data acquisition from inaccessible structural components such as bridges, tall buildings, and industrial structures, thereby improving inspection efficiency and safety. Zhou et al. (2025) developed an intelligent crack detection framework using UAV imagery combined with the DBE-YOLO network, achieving 96.79% detection accuracy and enabling 3D visualization of crack distribution for better structural interpretation. Similarly, Słoński (2025) integrated deep learning-based segmentation with DIC techniques to analyze long-term crack development in precast crane beams, demonstrating that combined optical and computational methods provide highly accurate non-destructive evaluation capabilities. Digital image correlation has also been extensively used to analyze deformation fields and crack propagation behavior under loading conditions. Huang et al. (2019) observed that cracks typically initiate in the interfacial transition zone (ITZ) and propagate progressively under stress, with material composition significantly influencing crack development patterns. Woods et al. (2021) further extended image-based analysis by introducing fractal dimension-based damage indices for post-earthquake assessment of reinforced concrete structures, eliminating the need for manual inspection. Despite these advancements, challenges such as sensitivity to noise, lighting variations, and complex surface textures still persist in image-based crack detection systems, as highlighted by Sreedhara et al. (2023), who emphasized the importance of calibration and error minimization in field applications. Therefore, the continuous development of robust, accurate, and computationally efficient digital image processing systems remains essential for advancing structural health monitoring and ensuring the long-term safety and sustainability of civil infrastructure systems.

II. RESEARCH BACKGROUND

Zarefa and Mirzaei (2026) highlighted that concrete structures were susceptible to degradation due to internal flaws and external stresses, with crack formation identified as a critical factor influencing their strength and durability. They noted that traditional condition assessment methods were often constrained by their limited ability to systematically detect and differentiate crack types. The study proposed a hybrid methodology in which manual crack evaluation was supplemented by classical image processing techniques, including Otsu-Thresholding and Canny Edge Detection. Through this integration, crack assessment was automated and enhanced, enabling more consistent identification and classification of cracks. The methodology was applied to real-world structures, where its effectiveness was demonstrated in detecting crack patterns across multiple scales and linking them to underlying structural causes. The authors concluded that the proposed approach could serve as a practical and resource-efficient tool to improve the consistency and reliability of structural assessments.

Hacıefendioğlu and Demir (2026) examined the application of deep learning technologies, particularly U-Net-based segmentation methods, for assessing earthquake-induced damages. They utilized a dataset derived from the Kahramanmaraş earthquake to train and test deep learning models aimed at detecting and quantifying structural damages such as concrete cracks. The study highlighted that the 2023 Kahramanmaraş earthquakes had emphasized the urgent need for rapid and accurate post-earthquake evaluations to ensure the safety and timely rehabilitation of affected reinforced concrete (RC) structures. Their findings indicated that deep learning models, especially those implementing U-Net architectures, provided notable improvements over conventional visual inspection techniques by enabling faster, more consistent, and more precise damage assessments. Reported intersection over union (IoU) scores of 0.737 for concrete cracks demonstrated the models' effectiveness in distinguishing specific damage patterns. The research concluded that such approaches were essential for efficient structural integrity assessment and for prioritizing repair and rehabilitation interventions in disaster-affected areas.

Zhou et al. (2025) emphasized the importance of regular crack detection for prolonging bridge service life. They noted that image data collected during bridge inspections were often complex to translate into physical information and to develop intuitive Three-Dimensional (3D) models incorporating crack details. To address these challenges, they proposed an intelligent crack detection approach for bridge surface damage using Unmanned Aerial Vehicles (UAVs), which involved a three-stage process of detection, quantification, and visualization. The study reported that the DBE-YOLO crack detection network improved feature extraction from complex backgrounds and enhanced multi-scale detection capabilities. Moreover, a comprehensive crack quantification method was integrated into the automated detection system, enabling accurate crack measurement and efficient processing. Crack information was mapped onto 3D models through camera pose computation for each image. Experimental evaluations on a concrete beam and urban bridge demonstrated high accuracy, with the DBE-YOLO network achieving 96.79% accuracy and an F1 score of 88.51%, while 3D models effectively represented crack distribution.

Słoński (2025) highlighted that the longevity and safety of concrete precast crane beams played a crucial role in maintaining the operational integrity of industrial infrastructure. The study indicated that the assessment of surface crack development in concrete structural elements during laboratory tests had traditionally been conducted using standard instruments such as linear-variable-differential transformers and strain gauges. Słoński proposed a novel methodology that combined a deep convolutional neural network for image segmentation with the digital image correlation (DIC) technique to evaluate the structural health of precast crane beams after over fifty years of service. The research explained how the U-Net deep learning architecture was adapted to detect and segment surface cracks, while DIC was employed to measure surface strains and displacements under load. The integration of these approaches was reported to enable non-destructive, accurate, and detailed analyses, facilitating early detection of deterioration and supporting predictive maintenance of aging industrial infrastructure, with initial field tests validating its effectiveness.

Shalaby et al. (2024) emphasized that early detection of cracks in concrete construction was crucial to prevent potential risks in later stages. They noted that traditional crack detection techniques were often unreliable and ineffective for identifying flaws on concrete surfaces. To address this, they proposed an intelligent algorithm as a supportive tool for authorities to monitor and assess the condition of buildings and bridges. The study aimed to develop an automatic crack detection model based on image processing technology and tested it on three different concrete surfaces: bridge decks, walls, and concrete cubes. Public datasets from SDNET (2018) and laboratory-prepared concrete cubes from Ain Shams University were applied to evaluate the model. The reported F1-scores were 98.87%, 97.43%, and 74.11% for bridge decks, walls, and cubes, respectively. The study highlighted that the proposed approach performed efficiently even on uneven surfaces with noise, voids, and stains, while maintaining transparency and lower computational cost compared with deep learning frameworks.

Sohaib, Jamil, and Kim (2024) highlighted the critical importance of early crack detection in concrete structures to prevent potential instability, noting that conventional manual inspection methods were time-consuming. They observed that existing automated crack detection algorithms, despite recent advancements, faced limitations in robustness, particularly in accurately identifying cracks against complex backgrounds while maintaining low inference times. To address these challenges, they proposed a novel ensemble mechanism employing multiple quantized You Only Look Once version 8 (YOLOv8) models for crack detection and segmentation. The authors reported that the model, when tested on diverse concrete crack datasets, achieved enhanced segmentation results with a minimum precision of 89.62% and an intersection-over-union score of 0.88, while reducing inference time per image to 27 milliseconds, reflecting at least a 5% improvement over other models. Their contributions were noted to include a robust ensemble approach, accelerated inference, and improved learning capabilities, making the model suitable for real-time infrastructure monitoring.

Sreedhara et al. (2023) highlighted that cracking in concrete structures was a pervasive issue that affected their serviceability, and they emphasized the necessity of accurately measuring and monitoring crack dimensions to determine repair and rehabilitation needs. They reported that two field studies had been conducted employing digital image processing to evaluate crack widths in concrete structures. The first study had compared measurements obtained through digital image processing, a handheld microscope, and a crack gauge card, while the second had applied digital image processing to assess end-region cracks in precast pretensioned concrete girders. They noted that guidance was provided for engineers intending to implement digital image processing in field studies. Moreover, they identified conditions under which digital image processing could introduce errors and discussed methodological limitations. Overall, their studies indicated that image processing techniques had been effective in field-based crack measurement and produced results comparable to those obtained via microscope evaluations.

Han et al. (2022) highlighted that cracking was one of the common indicators of damage in concrete structures and noted that traditional computer vision techniques were commonly employed for crack detection, though these methods were still limited in intelligence and precision. They suggested that deep convolutional neural networks (DCNNs) had recently enhanced performance in visual tasks. The study proposed a hybrid approach combining CNN and digital image processing to identify cracks in images. Using transfer learning, an AlexNet-based CNN was reportedly trained effectively on a small dataset, achieving 98.26% accuracy on new test data. The authors explained that crack segmentation was then performed using a threshold-based method, and the resulting crack mask comprised all segmented regions. They observed that transfer learning reduced both data requirements and computational cost while maintaining high accuracy. The findings emphasized that precise crack mask detection could support automated crack measurement and fracture type classification.

Woods et al. (2021) highlighted that damage assessment in postearthquake reconnaissance of civil structures had traditionally depended on the judgment of experienced site inspectors. They proposed a method to eliminate the need for on-site inspections by enabling automatic postdisaster structural damage assessment of reinforced concrete (RC) structures. The study employed digital image correlation to detect cracks in RC elements and correlated the analyzed crack patterns to a damage index using fractal dimension. The method was applied to track damage progression in a planar RC shear wall and a cylindrical RC containment vessel under laboratory reversed cyclic loading. The authors compared the results from the proposed damage index with both quantitative and qualitative indices previously used to evaluate RC damage levels. They also extended the method to an RC shear wall subjected to actual earthquake ground motion via hybrid simulation, demonstrating its capability to monitor damage progression in realistic scenarios. Based on the findings, damage grades were suggested to relate the computed index to specific damage levels.

Shahrokhinasab et al. (2020) highlighted those traditional methods for calculating crack widths in concrete structures had primarily relied on manual and non-systematic data collection, heavily depending on personal judgment. They noted that these approaches were time-consuming and prone to inevitable human errors, which had led researchers in recent years to focus more on novel detection and monitoring techniques. Among these, image-based methods were identified as particularly significant, utilizing field photographs to estimate parameters such as crack occurrence, location, severity, length, width, and depth. The study indicated that monitoring crack propagation over time through sequential images was a key design objective of these approaches. While image processing techniques were reported to misidentify surface noise as cracks, targeting methods were found to have limitations in accurately determining crack locations. These challenges, they argued, had encouraged the development of more advanced methods, including Digital Image Correlation (DIC) and mathematical tools such as Wavelet Transform (WT), to minimize such errors.

Huang et al. (2019) investigated the deformation distribution and crack propagation of concrete under axial compression using the digital image correlation (DIC) method. They established a novel analysis procedure and numerical program for the DIC method, where the water-cement (W/C) ratio was considered a key parameter. The displacements and strains of coarse aggregate, cement mortar, and the interface transition zone (ITZ) were obtained and verified experimentally. They reported that axial displacement was distributed non-uniformly during loading, with ITZs and cement mortar exhibiting larger displacements than coarse aggregates before macrocrack formation. The influence of W/C on horizontal displacement was found to be minimal. Transverse and shear deformation concentration areas (DCAs) appeared when stress reached 30%–40% of peak stress, crossing cement mortar, ITZs, and aggregates, while axial DCAs predominantly surrounded aggregates. Higher W/C ratios were associated with larger and more numerous DCAs. Crack propagation was observed to initiate in ITZs, and higher W/C specimens exhibited more widespread but narrower cracks, indicating a notable effect of W/C on concrete deterioration characteristics.

III. KEY FINDINGS FROM STUDY

Author (Year)	Methodology / Approach	Key Findings	Research Contribution to Study
Zarefa & Mirzaei (2026)	Hybrid image processing (Otsu thresholding, Canny edge detection) + manual assessment	Improved consistency in crack detection and classification across structures	Established foundation for hybrid image-processing-based crack assessment
Hacıefendioğlu & Demir (2026)	Deep learning (U-Net) trained on earthquake damage dataset	IoU of 0.737 for crack detection; faster and more accurate than manual inspection	Demonstrated effectiveness of deep learning in post-earthquake damage evaluation

Zhou et al. (2025)	UAV-based imaging + DBE-YOLO object detection + 3D modeling	Achieved 96.79% accuracy and F1 score of 88.51%	Introduced aerial-based automated crack detection with 3D visualization
Słoński (2025)	U-Net deep learning + Digital Image Correlation (DIC)	Accurate crack segmentation and strain measurement in aging beams	Combined optical + AI-based methods for structural health monitoring
Shalaby et al. (2024)	Classical image processing-based automated crack detection	High F1-scores: 98.87% (bridges), 97.43% (walls)	Demonstrated low-cost and efficient crack detection without deep learning
Sohaib, Jamil & Kim (2024)	Ensemble YOLOv8 models for detection and segmentation	Precision 89.62%, IoU 0.88, real-time processing (27 ms/image)	Improved real-time crack detection using ensemble deep learning
Sreedhara et al. (2023)	Digital image processing compared with microscope & crack gauge	Image processing showed comparable accuracy in field crack measurement	Validated practical use of image processing for field crack width measurement
Han et al. (2022)	CNN (AlexNet) + image processing (thresholding)	Accuracy of 98.26% with transfer learning	Hybrid AI + image processing approach reduced data requirement
Woods et al. (2021)	Digital Image Correlation + fractal dimension damage index	Enabled automated post-earthquake damage assessment	Introduced image-based damage index for structural condition evaluation
Shahrokhinasab et al. (2020)	Review of image-based crack detection methods	Identified issues like noise misclassification and location errors	Highlighted need for advanced DIC and wavelet-based methods
Huang et al. (2019)	Digital Image Correlation (DIC) analysis of concrete deformation	Cracks initiate in ITZ; higher W/C increases crack propagation	Provided insight into material-level crack development behavior

IV. CONCLUSION

The reviewed literature collectively indicated that digital image processing and artificial intelligence-based techniques had significantly advanced the field of crack detection and structural damage assessment in concrete structures. It had been observed that traditional inspection methods, which relied heavily on manual observation and subjective judgment, were limited in accuracy, consistency, and scalability, particularly in large-scale infrastructure systems. Researchers such as Shahrokhinasab et al. (2020) had emphasized that conventional approaches were prone to human error and time inefficiency, thereby necessitating the development of automated and more reliable techniques. In response to these limitations, classical image processing methods such as edge detection, thresholding, and segmentation had been widely adopted, demonstrating improved efficiency in identifying crack patterns. Studies by Zarefa and Mirzaei (2026) and Shalaby et al. (2024) had confirmed that hybrid approaches combining manual assessment with image processing algorithms provided a cost-effective and relatively accurate solution for structural evaluation, particularly in resource-constrained environments. However, the emergence of deep learning and machine learning techniques had further transformed this domain by enabling higher precision, automation, and real-time analysis capabilities. Models such as U-Net, YOLOv8, and CNN-based architectures had demonstrated superior performance in crack detection tasks, as evidenced by Hacıefendioğlu and Demir (2026), Han et al. (2022), and Sohaib, Jamil, and Kim (2024), who reported high accuracy and intersection-over-union scores along with significantly reduced processing times. Moreover, the integration of UAV-based imaging systems and digital image correlation techniques had expanded the applicability of automated crack detection to complex and inaccessible structural environments, as demonstrated by Zhou et al. (2025) and Słoński (2025). These advancements had enabled not only crack detection but also quantification, visualization, and structural health monitoring in three-dimensional space. Despite these significant developments, challenges such as sensitivity to environmental noise, variation in lighting conditions, and limitations in generalization across different structural surfaces had still persisted. Therefore, it had been concluded that while digital image processing and AI-based techniques had substantially improved the accuracy and efficiency of crack detection systems, further research was still required to enhance robustness, adaptability, and real-time deployment capabilities for large-scale infrastructure monitoring and maintenance applications.

V. FUTURE SCOPE

- **Integration of Advanced Deep Learning Architectures:** Future research may focus on the development and application of more advanced deep learning models such as Vision Transformers (ViTs), hybrid CNN-Transformer networks, and attention-based architectures to improve crack detection accuracy, especially in complex and noisy environments.
- **Real-Time Structural Health Monitoring Systems:** There is a strong scope for designing fully automated real-time monitoring systems that can continuously analyze structural conditions using live video feeds, enabling immediate detection of cracks and structural anomalies in critical infrastructure.
- **UAV and Robotics-Based Inspection Systems:** The use of unmanned aerial vehicles (UAVs), drones, and autonomous robotic systems can be further enhanced for large-scale inspection of bridges, dams, tunnels, and high-rise buildings, reducing human risk and improving data collection efficiency.
- **Multimodal Data Fusion Techniques:** Future studies may integrate multiple data sources such as thermal imaging, infrared sensors, LiDAR, and acoustic emission data with digital image processing to improve crack detection reliability and reduce false positives.
- **3D Structural Modeling and Digital Twin Technology:** The development of digital twin models of infrastructure systems can enable continuous simulation and monitoring of crack evolution in real time, improving predictive maintenance strategies and lifecycle management of structures.
- **Edge Computing and IoT Integration:** Embedding crack detection algorithms into edge devices and IoT-based sensor networks can enable decentralized processing, faster decision-making, and reduced dependency on cloud computing systems.
- **Improved Generalization Across Diverse Structures:** Future research should focus on improving model adaptability so that crack detection systems can perform consistently across different materials, surface textures, lighting conditions, and environmental scenarios.
- **Automated Crack Severity Classification:** Development of intelligent systems capable of not only detecting cracks but also classifying their severity levels (minor, moderate, severe) and predicting structural risk would enhance maintenance planning.
- **Large-Scale Annotated Dataset Development:** The creation of diverse, high-quality, and publicly available datasets covering different types of concrete structures and environmental conditions is essential for improving model training and benchmarking.

- **Sustainable Infrastructure Monitoring Systems:** Future work may focus on designing energy-efficient, low-cost, and scalable monitoring systems that support long-term sustainability of civil infrastructure while reducing inspection and maintenance costs.

REFERENCES

1. Zarefa, G., & Mirzaei, Z. (2026). A methodology for qualitative assessment of cracks in structural concrete using a combination of image processing techniques and knowledge-based models. *Australian Journal of Structural Engineering*, 1-18.
2. Hacıefendioğlu, K., & Demir, S. (2026). Deep Learning–Based Automated Crack Detection for Post-Earthquake Damage Assessment in Reinforced Concrete Structures. *Advances in Civil Engineering*, *2026*(1), 6845779.
3. Zhou, L., Jia, H., Jiang, S., Xu, F., Tang, H., Xiang, C., ... & Chen, L. (2025). Multi-scale crack detection and quantification of concrete bridges based on aerial photography and improved object detection network. *Buildings*, *15*(7), 1117.
4. Słoński, M. (2025). Assessment of Cracking Development in Concrete Precast Crane Beams Using Optical and Deep Learning Methods. *Materials*, *18*(4), 731.
5. Shalaby, Y. M., Badawy, M., Ebrahim, G. A., & Abdelalim, A. M. (2024). Condition assessment of concrete structures using automated crack detection method for different concrete surface types based on image processing. *Discover Civil Engineering*, *1*(1), 81.
6. Sohaib, M., Jamil, S., & Kim, J. M. (2024). An ensemble approach for robust automated crack detection and segmentation in concrete structures. *Sensors*, *24*(1), 257.
7. Sreedhara, S., Sorensen, T. J., Poursaee, A., & Ross, B. E. (2023). Practical application of digital image processing in measuring concrete crack widths in field studies. *Practice Periodical on Structural Design and Construction*, *28*(1), 05022006.
8. Han, X., Zhao, Z., Chen, L., Hu, X., Tian, Y., Zhai, C., ... & Huang, X. (2022). Structural damage-causing concrete cracking detection based on a deep-learning method. *Construction and Building Materials*, *337*, 127562.
9. Woods, J. E., Yang, Y. S., Chen, P. C., Lau, D. T., & Erochko, J. (2021). Automated crack detection and damage index calculation for RC structures using image analysis and fractal dimension. *Journal of Structural Engineering*, *147*(4), 04021019.
10. Shahrokhinasab, E., Hosseinzadeh, N., Monirabbasi, A., & Torkaman, S. (2020). Performance of image-based crack detection systems in concrete structures. *Journal of Soft Computing in Civil Engineering*, *4*(1), 127-139.
11. Huang, Y., He, X., Wang, Q., & Xiao, J. (2019). Deformation field and crack analyses of concrete using digital image correlation method. *Frontiers of Structural and Civil Engineering*, *13*(5), 1183-1199.