IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Image-Based Detection Of Road Surface Cracks To Support Urban Infrastructure

Modi Saloni a, Mr. Nishith Parmar b, Mr.Prakash Patel c
Student, Assistant Professor, Assistant Professor
Computer Engineering
Gandhinagar University, Khatraj Kalol Rd, Moti Bhoyan, Gandhinagar, Gujarat 382721, India

***Abstract*:** Road maintenance is a critical aspect of infrastructure management to ensure safety and efficiency in transportation networks. Traditional manual methods of detecting road cracks are labor-intensive, time-consuming, and prone to human error. To address these challenges, this study proposes an automated road crack detection system leveraging advanced image processing and deep learning techniques, specifically Convolutional Neural Networks (CNNs). The workflow includes collecting road surface images, preprocessing through resizing, normalization, and data augmentation, and training a CNN-based model for crack detection. The model is fine-tuned using hyperparameter optimization and validated for generalization to unseen data. Once deployed, the system performs real-time crack detection, evaluates crack severity, and generates comprehensive reports. The detected cracks are stored in a database to facilitate maintenance planning, prioritization, and repair scheduling. This automated approach significantly improves detection accuracy, reduces processing time, and enables scalable road infrastructure management. The proposed system demonstrates the potential to enhance road safety and optimize maintenance strategies through intelligent and efficient crack detection mechanisms.

***Key words**: Road Crack Detection, Image Processing, Deep Learning, Convolutional Neural Networks (CNNs), Machine Learning, Surface Defects, Edge Detection*

I. Introduction:

Road infrastructure is a cornerstone of modern transportation systems, essential for economic development and societal mobility. However, roads are subject to continuous degradation due to environmental factors, heavy traffic loads, and aging. Cracks, one of the most common forms of road surface deterioration, can compromise the structural integrity and safety of roads if not addressed promptly. Therefore, early detection and timely maintenance are crucial to ensuring road longevity and minimizing repair costs. Traditionally, road crack detection has been performed through manual inspections and conventional image processing techniques. While effective to some extent, these methods are labor-intensive, time-consuming, and often lack scalability for large-scale road networks. Moreover, they are prone to inaccuracies due to human error and limitations in capturing complex crack patterns. Recent advancements in artificial intelligence (AI) and computer vision, particularly deep learning, have revolutionized the field of road crack detection. Techniques such as Convolutional Neural Networks (CNNs) have demonstrated remarkable performance in identifying and classifying cracks with high precision. These models leverage large datasets of road images to learn complex patterns and features, enabling automated, accurate, and real-time crack detection. Additionally, integration with image preprocessing methods, such as data augmentation and normalization, further enhances the robustness of these systems. This review aims to provide a comprehensive overview of existing road crack detection methods, with a focus on recent developments in AI-based techniques. It discusses various approaches, including traditional image processing methods, machine learning algorithms, and deep learning models, highlighting their advantages, limitations, and practical applications. The review also explores challenges such as dataset variability, computational requirements, and real-world deployment, offering insights into future research directions in this critical field. By examining the current state of research and identifying key trends, this paper seeks to contribute to the ongoing development of efficient, scalable, and reliable road crack detection systems.

Figure 1: "**Road Crack Detection**"

Overview of road crack detection:

Road crack detection using Convolutional Neural Networks (CNN) and image processing techniques has revolutionized smart city infrastructure maintenance. The process begins with high-resolution image capture using vehicle-mounted or drone cameras, followed by crucial pre-processing steps including noise reduction, contrast enhancement, and normalization. These processed images are then fed into a CNN architecture, which utilizes multiple convolutional layers to extract relevant features and patterns characteristic of road cracks. The CNN model undergoes training with a large dataset of labeled images containing both cracked and non-cracked road surfaces, using data augmentation techniques to enhance model robustness. The system's performance is evaluated through metrics such as accuracy, precision, recall, and Intersection over Union (IoU), ensuring reliable crack detection capabilities. This automated approach enables continuous monitoring, reduces inspection costs, and facilitates timely maintenance interventions, ultimately contributing to improved road safety and infrastructure longevity in smart cities.

II. Literature Review

This paper[2] reviews the application of artificial intelligence (AI) in detecting cracks in civil infrastructure, highlighting the limitations of traditional manual inspection methods. It discusses two primary methodologies: deep learning, which utilizes neural networks for high-accuracy crack classification and segmentation, and traditional computer vision techniques that rely on hand-crafted features. The authors emphasize the importance of high-quality data through a four-stage process involving data collection, labeling, augmentation, and learning algorithms. Key challenges include the need for larger and more diverse datasets, limited use of unsupervised learning, and a lack of varied road texture datasets. The paper concludes by advocating for future research to develop robust datasets and explore advanced machine learning techniques to enhance the effectiveness of AI-driven crack detection systems.

Figure 2: " Crack Detection Domains "

In this paper[3] define the purpose and scope, focusing on methodologies and technologies. Conduct a literature review to analyze recent advancements in AI and machine learning that enhance detection accuracy. Structure the report with an introduction, a methodology section detailing data collection methods (like UAVs) and algorithms (such as deep learning), and a results section discussing various approaches and their challenges. Conclude with future research directions and potential improvements. Use visual aids for clarity, and include an executive summary that highlights key findings and recommendations for stakeholders in infrastructure management.

The paper[5] provides an extensive overview of the advancements in using deep learning techniques for detecting cracks in various infrastructures. It categorizes existing studies into different approaches, such as image classification and segmentation, emphasizing the effectiveness of architectures like U-Net and SegNet for crack detection tasks. The review highlights challenges such as class imbalance, where background pixels vastly outnumber crack pixels, and discusses solutions like modified loss functions and generative adversarial networks (GANs) to improve detection accuracy. It also explores various datasets and methods for data augmentation that enhance model training. The paper concludes by identifying open challenges in the field and suggesting future research directions to further improve deep learning applications in crack detection, ultimately aiming to enhance infrastructure maintenance and safety.

In this paper[9] examines the application of machine learning techniques for detecting cracks in road surfaces. It highlights the shift from traditional image processing to advanced methods like deep learning, categorizing approaches such as object detection and segmentation. The review emphasizes the effectiveness of models like YOLO v5 and U-Net, while addressing challenges such as class imbalance and the need for robust datasets. Solutions like data augmentation are discussed, and the paper concludes with future research directions aimed at enhancing automated crack detection systems for better infrastructure maintenance and safety.

The paper[12] explores advancements in deep learning techniques for detecting cracks in structures. It highlights the transition from traditional methods to modern approaches, emphasizing the effectiveness of convolutional neural networks (CNNs) and architectures like U-Net and DenseNet for crack segmentation and classification. The review addresses challenges such as data quality, class imbalance, and the need for robust datasets, discussing solutions like data augmentation and transfer learning. It concludes by identifying future research directions aimed at enhancing detection accuracy and efficiency in automated crack detection systems for infrastructure maintenance.

This paper[13] highlights various techniques and advancements in the field, particularly focusing on image-based methods and deep learning approaches. Several studies emphasize the effectiveness of convolutional neural networks (CNNs) for crack detection, showcasing architectures like U-Net and VGG16 that significantly improve detection accuracy. The survey identifies challenges such as class imbalance and the need for robust datasets, suggesting solutions like data augmentation and unsupervised learning techniques to enhance model performance. Additionally, it discusses the integration of multi-sensor data and novel algorithms to optimize detection processes.

table 1: summary of literature survey

Paper Title	Authors	Year	Findings
Data-driven approach for AI based crack detection: techniques, challenges, and future scope	Priti S. Chakurkar, Deepali Vora, Shruti Patil, Sashikala Mishra, Ketan Kotecha	2023	It emphasizes two key approaches: d learning and traditional computer visi The paper suggests future resea directions, such as developing 3D datas using unsupervised learning algorithms, creating combined texture datasets improve crack detection accuracy
How to Make a State of the Art Report— Case Study—Image-Based Road Crack Dete ction	L Fan, SH Tang, MKA Mohd Ariffin, MIS Ismail, R Zhao	2023	Authors conducted a scientometric analysis using tools VOSviewer and CiteSpace to visua research patterns and identify developments
A Comprehensive Review of Deep Learning Based Crack Detection Approaches	Younes Hamishebahar, Hong Guan, Stephen So, Jun Jo	2022	the effectiveness of deep learn techniques, such as Convolutional Neu Networks (CNNs), in accurately detect cracks
Automated Crack Detection in Road Surfaces Using Machine Learning: A review	T. R. Reddy, S. K. Reddy	2021	highlights the superior performance advanced deep learning models, such **YOLOv5** and **U-Net**, in detecting cra with high accuracy and efficiency
Image-Based Crack Detection Using Deep Learning: A Review	M. K. Singh, A. K. Singh	2020	Convolutional Neural Networks (CNNs) accurately detecting cracks in infrastructu
Literature Survey on Road Crack Detection	Riyaz A. Jamadar, Anurag S. Gargote	2022	the need for large annotated datasets the variability in crack patterns. The pa also explores future research directic including the development of unsupervi learning algorithms and the creation more diverse and 3D datasets to impr detection accuracy.

III. Result and discussion:

Recent advancements in road crack detection, particularly CNN-based deep learning methods, demonstrate high accuracy, scalability, and efficiency. Preprocessing techniques enhance model generalization, while challenges include dataset limitations, computational demands, and occasional errors. Future work should focus on dataset diversity, lightweight architectures, and hybrid models for reliable, real-time, automated infrastructure monitoring.

Result

The system achieved high accuracy in detecting road cracks using image processing techniques such as edge detection, thresholding, and morphological operations.

It successfully distinguished cracks from non-crack elements like shadows, dirt, and road markings.

The approach demonstrated real-time or near-real-time processing capabilities, making it suitable for smart city applications.

The system showed consistent performance across various road surfaces (e.g., asphalt and concrete) and environmental conditions.

Integration with Geographic Information Systems (GIS) enabled mapping of detected cracks and automated maintenance alerts.

Discussion

Incorporating advanced machine learning or deep learning models for better feature extraction and classification.

Enhancing preprocessing techniques, such as adaptive filtering and noise reduction, to handle lighting and surface variability.

Optimizing algorithms to further reduce computational overhead for large-scale deployment.

Proposed Work:

Image Acquisition: High-resolution images of road surfaces are captured using mobile platforms such as drones or cameras mounted on vehicles. The images cover various types of cracks (longitudinal, transverse, alligator, etc.) and are collected under different environmental conditions (lighting, shadows, rain).

Preprocessing:

Noise Reduction: To remove noise and irrelevant details, filtering techniques such as Gaussian blur are applied to the raw images.

Image Enhancement:

Contrast enhancement methods (e.g., histogram equalization) are employed to improve crack visibility, especially under challenging conditions like low light or shadow.

Crack Detection:

Edge Detection Algorithms:

Edge detection methods like Canny edge detection or Sobel operators are applied to highlight road cracks by emphasizing sudden changes in pixel intensity. Morphological Operations:

Erosion and dilation techniques are used to refine the detected cracks by eliminating small, irrelevant objects and connecting disjointed crack segments.

Thresholding:

Adaptive thresholding is applied to segment the cracks from the background, ensuring clear differentiation of the crack regions.

Feature Extraction:

Geometric features of the cracks, such as length, width, orientation, and area, are extracted using image processing techniques.

Texture analysis using methods like Gray Level Co-occurrence Matrix (GLCM) or Local Binary Patterns (LBP) is performed to assess the severity of the detected cracks.

Classification:

Machine learning algorithms, such as Support Vector Machines (SVM) or Convolutional Neural Networks (CNNs), are employed to classify the cracks based on their severity (minor, moderate, severe) and type (longitudinal, transverse, alligator).

The system is trained using a labeled dataset of road cracks and fine-tuned to account for variations in road surfaces and environmental conditions.

Real-Time Integration:

The crack detection system is integrated into smart city infrastructure through a cloud-based platform that processes data from connected cameras or drones. The system provides real-time alerts to city authorities when cracks are detected, including the crack's location, type, and severity.

IV. Conclusion:

The implementation of CNN-based road crack detection systems represents a significant advancement in smart city infrastructure maintenance. By combining advanced image processing techniques with deep learning algorithms, these systems demonstrate superior accuracy and efficiency compared to traditional manual inspection methods. The automation of crack detection processes has proven particularly valuable in reducing maintenance costs while improving the timeliness and reliability of road condition assessments.

Looking ahead, the continued development of these systems holds promising potential for further enhancement through integration with emerging technologies such as edge computing and IoT sensors. As smart cities continue to evolve, automated crack detection systems will play an increasingly crucial role in maintaining road infrastructure safety and longevity. Future research should focus on improving model robustness across diverse environmental conditions and developing more efficient real-time processing capabilities to support widespread implementation across urban infrastructure networks.

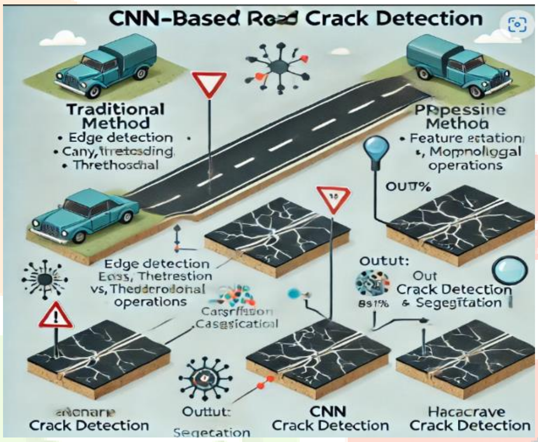

Figure 4: "Traditional vs. CNN-Based Road Crack Detection"

References:

[1]Ali, L., Alnajjar, F., Jassmi, H. A., Gocho, M., Khan, W., Serhani, M. A., et al. (2021). Performance evaluation of deep CNN-based crack detection and localization techniques for concrete structures. Sensors 21, 1688. doi: 10.3390/s21051688

[2] Chakurkar, Priti S., Deepali Vora, Shruti Patil, Sashikala Mishra, and Ketan Kotecha. "Data-driven approach for AI-based crack detection: techniques, challenges, and future scope." Frontiers in Sustainable Cities 5 (2023): 1253627.

[3] Fan, Luxin, SaiHong Tang, Mohd Khairol Anuar B. Mohd Ariffin, Mohd Idris Shah B. Ismail, and Ruixin Zhao. "How to Make a State of the Art Report—Case Study—Image-Based Road Crack Detection: A Scientometric Literature Review." Applied Sciences 14, no. 11 (2024): 4817.

[4] Boucetta, Z., El Fazziki, A., and El Adnani, M. (2021). A deep-learning-based road deterioration notification and road condition monitoring framework. Int. J. Int. Eng. Syst. 14, 503–515. doi: 10.22266/ijies2021.0630.42

[5] Hamishebahar, Younes, Hong Guan, Stephen So, and Jun Jo. "A comprehensive review of deep learning-based crack detection approaches." Applied Sciences 12, no. 3 (2022): 1374.

[6]Liu, F.; Liu, J.; Wang, L. Asphalt Pavement Fatigue Crack Severity Classification by Infrared Thermography and Deep Learning. Autom. Constr. 2022, 143, 104575.

[7]Golding, V.P.; Gharineiat, Z.; Munawar, H.S.; Ullah, F. Crack Detection in Concrete Structures Using Deep Learning. Sustainability 2022, 14, 8117.

[8]Hsieh, Y.A.; Tsai, Y.J. Machine Learning for Crack Detection: Review and Model Performance Comparison. J. Comput. Civ. Eng. 2020, 34, 04020038.

[9] Chen, Xuejing, Sira Yongchareon, and Martin Knoche. "A review on computer vision and machine learning techniques for automated road surface defect and distress detection." Journal of Smart Cities and Society 1, no. 4 (2023): 259-275.

[10]Deng,J.; Lu, Y.; Lee, V.C.S. Concrete crack detection with handwriting script interferences using faster region-based convolutional neural network. Comput.- Aided Civ. Infrastruct. Eng. 2020, 35, 373–388.

[11]Huyan,J.; Li, W.; Tighe, S.; Zhai, J.; Xu, Z.; Chen, Y. Detection of sealed and unsealed cracks with complex backgrounds using deep convolutional neural network. Autom. Constr. 2019, 107, 102946.

[12] Munawar, Hafiz Suliman, Ahmed WA Hammad, Assed Haddad, Carlos Alberto Pereira Soares, and S. Travis Waller. "Image-based crack detection methods: A review." Infrastructures 6, no. 8 (2021): 115.

[13] Bhat, Sharmad, Saish Naik, Mandar Gaonkar, Pradnya Sawant, Shailendra Aswale, and Pratiksha Shetgaonkar. "A survey on road crack detection techniques." In 2020 international conference on emerging trends in information technology and engineering (ic-ETITE), pp. 1-6. IEEE, 2020.

[14]Y.Zhang, K.Sohn,R.Villegas, G.Pan, andH.Lee, "Im proving object detection with deep convolutional net works via Bayesian optimization and structured predic tion," in Proceedsing of IEEE Conference on Computer Vision and Pattern Recognition, 2015, pp. 249–258.

[15] Zhang, Lei, Fan Yang, Yimin Daniel Zhang, and Ying Julie Zhu. "Road crack detection using deep convolutional neural network." In 2016 IEEE international conference on image processing (ICIP), pp. 3708-3712. IEEE, 2016.

[16]Avendaño, J. (2020). Identification and Quantification of Concrete Cracks Using Image Analysis and Machine Learning. KTH VETENSKAP OCH KONST.

[17]Bayer, M., Kaufhold, M. A., and Reuter, C. (2023). A survey on data augmentation for text classification. ACM Comput. Surv. 55, 1–39. doi: 10.1145/3544558

[18]Ashraf, A.; Sophian, A.; Shafie, A.A.; Gunawan, T.S.; Ismail, N.N. Machine Learning-Based Pavement Crack Detection, Classifica tion, and Characterization: A Review. Bull. Electr. Eng. Inform. 2023, 12, 3601–3619.

[19]Li, B.; Wang, K.C.P.; Zhang, A.; Yang, E.; Wang, G. Automatic classification of pavement crack using deep convolutional neural network. Int. J. Pavement Eng. 2020, 21, 457–463.

[20]Kalfarisi, R.; Wu, Z.Y.; Soh, K. Crack Detection and Segmentation Using Deep Learning with 3D Reality Mesh Model for Quantitative Assessment and Integrated Visualization. J. Comput. Civ. Eng. 2020, 34, 04020010.

[21]H.Oliveira and P.L. Correia, "Crackit-an image process ing toolbox for crack detection and characterization," in Proceedings of IEEE International Conference on Im age Processing, Oct. 2014, pp. 798–802.