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Review of Pavement Crack Types and Their Significance

Fan Luxin[1*], Tang Sai Hong[1*], M Ariffin[1], MIS Ismail[1], Zhao Ruixin[1]

[1] Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia

*Corresponding Author: gs59924@student.upm.edu.my , saihong@upm.edu.my

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Abstract: *This essay examines the significant importance of pavement distress detection, specifically in the capacity to identify and categorize various forms of cracks, in order to uphold road safety. This study explores the impact of technical breakthroughs on the detection and classification of pavement cracks, leading to notable improvements in road maintenance and accident prevention. The essay additionally explores a range of studies that indicate a connection between pavement conditions and traffic safety, including the association between pavement age and the likelihood of accidents, as well as the influence on the severity of crashes. This analysis serves to illustrate the paramount significance of maintaining pavement integrity in order to ensure traffic safety. The essay foresees future progress in crack detection techniques, highlighting their crucial role in the construction of safer road networks and the improvement of public safety.*

Keywords: Crack Types, Traffic Safety, Influence

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1. Introduction

According to Yan and Zhang (2023), pavement distress encompasses many issues, such as cracking, patching, and potholes. Categorizing pavement cracks is a crucial element of road upkeep and security. Different forms of cracks, including longitudinal, transverse, and alligator cracks, among others, possess unique features and have significant implications for the stability of pavements. The utilization of sophisticated methodologies for the identification and categorization of cracks is imperative in order to achieve optimal pavement management (Cao et al., 2020; N. et al., 2021; Rodriguez-Lozano et al., 2020). In Figure 2.2, the labels for six types of damage are shown: longitudinal cracks (LC), transverse cracks (TC), alligator cracks (AC), oblique cracks (OC), repair (RP), and potholes (PH).

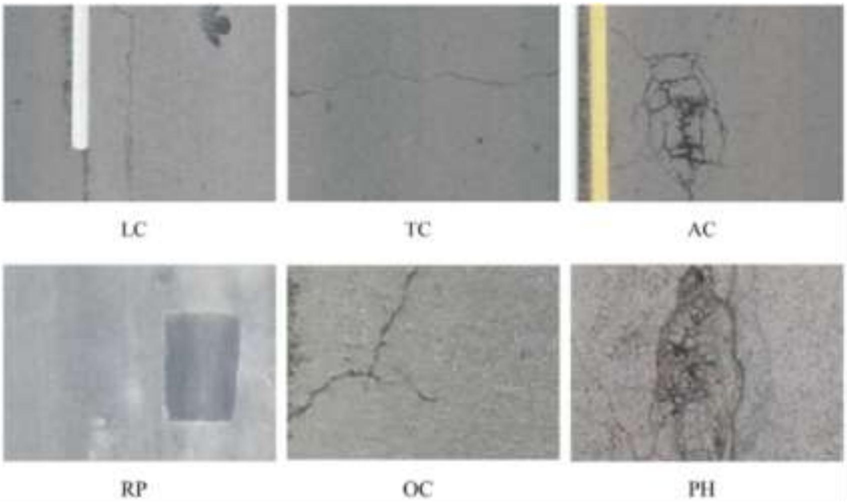

Figure 1: Sample Images of Pavement Distresses (Yan & Zhang, 2023)

Various forms of pavement cracks can have a substantial impact on the safety of roadways. Comprehending the gravity and consequences of different types of cracks is essential for prompt maintenance and the prevention of accidents (Gao, 2022).

2. Pavement Crack Classification Methods and Future Research Challenges

Oliveira's (2013) research produced a comprehensive system that uses automated techniques to identify and characterize fractures in road surfaces. This approach effectively eliminates the requirement for manually labeled samples. The initial crack identification in this system utilized unsupervised training, whereas a distinct process was employed to classify crack kinds. The assignment of labels and severity levels was based on the Portuguese Distress Catalog. The study's methodology was noteworthy due to its innovative approach to evaluating fracture width. In order to assign severity levels according to the Portuguese Distress Catalog's criteria, this study's methodology involved computing the mean width of each identified crack. The severity levels ranged from Level 1, which was defined by closed cracks with a width of up to 2 mm, to Level 3, which was defined by open cracks with a width of above 2 mm and damaged edges. The technology successfully quantified the width of cracks at the pixel level by utilizing the structural framework of the fracture. This study did not distinguish between Level 2 (open cracks larger than 2 mm without damaged edges) and Level 3 severity, though. This suggests that there is room for improvement in accurately differentiating between these two degrees of crack severity.

Koch's (2015) analysis primarily centered on the evaluation of the visual state of civil infrastructure, with a particular emphasis on the significance of computer vision in the identification of defects in concrete and asphalt. The report examined the progress, constraints, and forthcoming obstacles in this field. A support vector machine, trained on seven characteristics, was used to categorize cracks into transverse, longitudinal, block, and alligator types. Significant constraints encompassed the requirement for manual input, difficulties with lighting in subterranean pipelines, and a scarcity of data for machine learning. This study suggested a number of possible areas for further research. These include improving automated crack detection methods, creating standard procedures for data collection and analysis, and looking into new imaging methods for checking underground pipes.

Amhaz (2016) proposed a approach that is entirely unsupervised for the purpose of automatically detecting cracks in 2D pavement photos. This algorithm incorporates minimal route localization and innovative post-processing techniques. The utilization of this methodology, which takes into account both the photometric and geometric attributes of images, greatly improves the quality and precision of image detection. The algorithm demonstrates superior performance compared to five established approaches, as it has been evaluated using both synthetic and real photos. One notable advantage of this approach lies in its capacity to locally determine the crack width, thus contributing a significant aspect to the categorization of pavement cracks. With the above feature, along with its unsupervised features and extensive picture processing, it represents a big step forward in the field of identifying pavement cracks.

In Gopalakrishnan's (2017) research, a Deep Convolutional Neural Network (DCNN) was utilized to automatically detect and classify pavement distress. The DCNN was trained on the ImageNet database, which was chosen to overcome the difficulty of training classifiers on photos of pavements with different surface types. The study demonstrated exceptional performance by employing a single-layer neural network classifier to accurately categorize pavement cracks into two distinct types: transverse cracks and longitudinal cracks. The classification technique employed deep transfer learning, utilizing the VGG-16 DCNN as a feature generator. This approach showcased successful fracture identification across various pavement types. Nevertheless, the study recognized the necessity for more training samples and the creation of distinct classifiers to improve performance. The study also emphasized several constraints, such as the issue of differentiating between cracks and joints in pavements with Portland Cement Concrete surfaces, difficulties in detecting cracks that are less than 2 mm broad, and the existence of artifacts in the images. This study have identified several future research problems. These issues include teaching classifiers to correctly predict how bad cracks will be, fine-tuning the DCNN for the classification task, and looking into ways to add more data to classifiers to make them more accurate.

The objective of Nhat-Duc's (2018) study was to contrast two approaches for automatically detecting pavement cracks. The first tactic made use of the Sobel and Canny algorithms, which differential flower pollination had optimized. The second approach utilized a Convolutional Neural Network (CNN) technique. The research showed that the CNN model was more accurate at classifying things than traditional edge detection methods. This shows that it can be used for regular pavement inspections. The paper employed deep learning with CNN to categorize pavement cracks into many categories, such as longitudinal, transverse, alligator, oblique cracks, repairs, and potholes. The research emphasized the enhanced efficacy of CNN, ascribing it to the amalgamation of feature extraction and picture categorization. This integration facilitates autonomous learning and visualization of pavement images across various levels of abstraction. Nevertheless, computer vision-based infrastructure assessment has encountered several problems, including the presence of low contrast between cracks and the pavement background, the existence of different crack patterns, and the presence of inhomogeneous gray intensity inside crack objects. The intricate texture and shading conditions present in digital photographs limit the precision of thresholding-based models. This study underscored the necessity for additional investigation in order to enhance automation in the realm of real-world crack detection and optimize the efficacy of pavement crack detection models.

Li's (2020) research presented a novel approach that utilizes deep CNN to automatically classify picture patches from three-dimensional pavement photographs. The study encompassed the training of four CNN with different receptive field sizes. This approach yielded notable performance in terms of classification accuracy and yielded valuable insights into the impact of receptive field size on both training time and accuracy. The CNN were purposefully developed to categorize pavement patches into five distinct classifications, namely non-crack, longitudinal crack, transverse crack, block crack, and alligator crack. Significantly, the total precision of these CNN surpassed 94%, with one specific model, CNN-3, attaining an accuracy surpassing 96%. The excellent performance and dependability of CNN in classifying pavement cracks highlights their efficiency in processing 3D pavement photographs.

In Du's (2021) study, the YOLO network was employed for the purpose of object detection in order to identify and categorize pavement distress. The study utilized a dataset of significant scale and achieved notable levels of accuracy and processing speed, particularly when operating under excellent lighting conditions. The study categorized road surface fractures into longitudinal and transverse varieties according to the dimensions of the bounding box. Longitudinal cracks were detected when the length of the box surpassed its width, while transverse cracks were discovered when the width was greater. The study's notable accomplishments encompassed the creation of a very effective computer vision-driven approach for the identification and categorization of road surface distress. This method exhibited considerable potential in terms of both accuracy and efficiency. Nevertheless, the study encountered constraints as a result of the absence of depth dimension data in photographs, which impacted the precision of distress categorization. This study proposes several potential avenues for future research. Some of these are adding depth information to descriptions to make them more accurate, increasing the size of training samples to make networks more accurate, comparing different algorithms to see which ones work best, and looking into precision-recall and detection error trade-off curves to get even more accurate results.

Li's (2021) research presented a transfer learning pipeline that utilizes a generative adversarial network for data transfer and domain adaptation for model transfer. This pipeline enables the adaptation of deep learning models for pavement distress detection across various situations and camera settings. This approach improved the precision of the model in unfamiliar situations while minimizing the requirement for a large amount of training data. The study primarily concentrated on utilizing deep learning techniques to detect and classify pavement distress. It employed transfer learning to modify pre-trained models. The pavement distress classification encompassed various categories, including cracks, net-cracks, potholes, patch-cracks, patch-net, and patch-potholes. These types were appropriately labeled in both the training and testing datasets. The most important things that were done were making deep learning models work better than traditional methods and making models adapt to new situations more effectively while relying less on large amounts of annotated data. Nevertheless, the research encountered obstacles such as the requirement for a wide range of training datasets to enhance performance in multiple circumstances and the necessity to minimize false positives in detection algorithms. The study also brought attention to a number of unresolved issues, such as the need to look into more complex models and give priority to the inclusion of various datasets for cross-scene recognition.

Dong (2022) proposed a novel approach for detecting pavement distress using metric learning, which enables the identification of new categories from a small number of samples. The employed approach utilized a backend network to extract features and incorporated an attention mechanism within the metric module. As a result, notable enhancements in performance were observed on a dataset pertaining to pavement distress. The primary objective of the study was to identify and categorize different forms of pavement distress, including cracks, blocks, potholes, and alligators. The study introduced a new metric module that uses deep learning, primarily deep CNN, to extract distinguishing features from photos. The module focuses on identifying the characteristics of distressed regions. Furthermore, the model was optimized using a metric loss function, which aimed to increase inter-class variations while decreasing intra-class variations. According to this study the approach has shown commendable efficacy in few-shot classification trials conducted on a pavement distress dataset, surpassing the performance of existing state-of-the-art approaches.

Kheradmandi's (2022) literature review concentrated on the use of image-based techniques to identify pavement cracks. The review explored different segmentation methods, such as thresholding-based, edge-based, and data-driven approaches. The review provided significant insights into the enhancement of segmentation algorithms for the automatic detection of distress in pavement photographs. One crucial element of the review pertained to the utilization of crack width as a criterion for the classification of cracks. The article highlighted the efficacy of deep CNN in identifying pavement cracks, emphasizing their exceptional precision. Nevertheless, the study also highlighted the constraints of existing algorithms, including the lack of a universally accepted approach for extracting pavement cracks and the difficulties in attaining enhanced precision and expedited processing speeds. The review emphasized the significance of future research endeavors focused on addressing these obstacles and advancing segmentation techniques. Automated failure evaluation processes will greatly benefit from these methodologies, especially when dealing with different road surface characteristics and pavement textures.

Que (2023) proposed a novel approach that integrates Generative Adversarial Network (GAN) for data augmentation with a modified deep learning network, specifically an enhanced VGG model, to classify cracks in pavement. The implementation of this comprehensive methodology resulted in a notable improvement in the precision and effectiveness of categorizing many forms of pavement cracks, including horizontal, vertical, and alligator cracks, alongside potholes. The classification approach described in this study utilizes an improved GAN to generate a wide range of asphalt pavement crack images. Additionally, a modified VGG16 algorithm is employed as a feature extractor. The study's notable accomplishments encompassed the advancement of a refined GAN in the context of image formation, the formulation of a modified VGG16 algorithm for the purpose of crack classification, and the effective amalgamation of GAN and VGG16, resulting in enhanced precision in crack classification. Nevertheless, the research encountered obstacles such as the arduous task of manually gathering an extensive dataset of authentic crack images, as well as the necessity for a significant quantity of parameters and samples to effectively train the VGG Net. The study also highlighted several unresolved research obstacles in the field of computer vision-based infrastructure assessment. Some of these problems include the need to improve the crack image dataset by using GAN enhancement, make the classification algorithms for pavement cracks better, and test how well the proposed integrated model works.

According to a variety of studies conducted from 2013 to 2023, there has been significant advancement in the field of pavement crack detection and classification in recent years. Researchers have used a variety of methodologies to categorize pavement cracks, including

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conventional forms like longitudinal, transverse, and alligator cracks as well as the inclusion of crack width as a fundamental requirement for classification. From Oliveira's unsupervised training strategy in 2013 to Que's combination of GAN and deep learning in 2023, these methods have seen significant evolution. achievements, but there are still some challenges that remain in the sector. There is a huge challenge in developing automated and precise systems for detecting cracks, especially when it comes to adjusting these approaches to various and evolving pavement conditions. Furthermore, the recurring concerns revolve around the difficulty of gathering extensive and varied datasets for training purposes, as well as the need to minimize false positives in detection algorithms. According to future research, the main goals will be to make crack detection models more accurate and useful, to create more advanced segmentation methods, and to use cutting-edge technologies like deep learning and GAN to solve these problems. The use of these sophisticated techniques holds the potential to significantly transform the domain, enhancing the efficiency and dependability of pavement maintenance.

Table 1: Overview of Pavement Crack Classification Methods and Future Research Challenges

Researcher	Year	Classification Method	Future Challenges
Oliveira	2013	Severity levels based on crack width (wide, narrow cracks).	Refinement in distinguishing between different severity levels of cracks.
Koch	2015	Types of cracks: transverse, longitudinal, block, alligator.	Automated crack detection methods, data collection standardization, new imaging for buried pipe inspection.
Amhaz	2016	Crack width calculation for classification.	-
Gopalakrishnan	2017	Crack types: transverse and longitudinal.	More training samples, separate classifiers for pavement types, data augmentation techniques.
Nhat-Duc	2018	Crack types: longitudinal, transverse, alligator, oblique, repairs, potholes.	Automation improvement in real-world detection, enhanced pavement crack detection models.
B. Li	2020	Crack types: non-crack, longitudinal, transverse, block, alligator.	Diverse training datasets, reducing false positives.
Du	2021	Crack types based on bounding box dimensions: longitudinal and transverse.	Depth information incorporation, algorithm comparison, precision-recall analysis.
Y. Li	2021	Crack types: cracks, net-cracks, potholes, patch-cracks, patch-net, patch-potholes.	Advanced models, dataset diversity for cross-scene recognition.
Dong	2022	Various types of pavement distresses: cracks, blocks, potholes, alligators.	-
Kheradmandi	2022	Crack width as a criterion for classification.	Advanced segmentation methods for varying road surface qualities.
Que	2023	Crack types: horizontal, vertical, alligator cracks, potholes.	GAN augmentation for dataset expansion, improved classification algorithms, integrated model evaluation.

3. The Influence of Pavement Conditions on Road Safety

His (2005) have conducted research on the influence of road surface characteristics, particularly the depth and unevenness of ruts, on both traffic safety and ride comfort. This study employed regression analysis and a driving simulator to evaluate the correlation between road surface imperfections and accident rates on Swedish state roads. The findings demonstrated a positive correlation between increased unevenness (as measured by the International Roughness Index) and higher accident rates, even though ruts had a negligible impact on traffic safety. Furthermore, the research investigated the perspectives of drivers regarding the comfort of their rides and their inclination to invest in enhanced driving conditions, highlighting the importance of road surface quality in relation to driving comfort.

Utilizing Bayesian ordered logistic models, Lee's (2015) study primarily looked at the relationship between poor pavement conditions and the severity of crashes. The analysis of the study was categorized according to the speed of the road (low, medium, or high) and the kind of collisions (single/multiple vehicles). The findings indicate that substandard pavement conditions have a tendency to mitigate the severity of single-vehicle incidents on low-speed highways, while paradoxically exacerbating the severity of such collisions on high-speed routes. In contrast, in the case of multiple-vehicle incidents, the severity of the damage increased for all types of roads due to poor pavement conditions. The information provided is essential for transportation agencies to develop efficient pavement repair methods that can reduce the severity of traffic crashes.

Tsubota (2018) conducted an empirical analysis to investigate the correlation between the age of road pavement and the likelihood of traffic accidents. The research emphasized a deficiency in the existing pavement maintenance planning, which frequently neglects the consideration of traffic safety. The study employed Poisson regression analysis to estimate accident frequency, revealing a positive association between pavement age and accident risk. Notably, variations in accident risk were detected among different pavement types. The study emphasizes the significance of incorporating traffic safety factors into pavement management strategies.

Gao (2022) conducted an analysis on the initial development of cracks in cement concrete pavements at airports, with a specific emphasis on identifying the reasons and implementing preventive measures. The research emphasized the potential hazards associated with premature pavement cracks in relation to both aircraft safety and the durability of airport pavements. The study suggests a set of preventive techniques to manage the early creation of cracks in Tianjin Airport's deicing floor extension project. It highlights the need for timely intervention to preserve the integrity and safety of the pavement.

Table 2: Research on Pavement Conditions and Road Safety

Author	Year	Focus of Study	Key Findings
Ihs	2005	Impact of road surface conditions on traffic safety and ride comfort	Unevenness increases accident rates; ruts have minimal impact on safety.
Lee	2015	Relationship between pavement conditions and crash severity	Poor pavement conditions affect crash severity differently based on road speed and collision type.
Tsubota	2018	Link between pavement age and traffic accident risks	Older pavements are associated with higher accident risks; highlights the need for timely maintenance.
Gao	2022	Early crack formation in airport pavements	Early detection and prevention of cracks are crucial for flight safety and pavement longevity.

In conclusion, the combined research by Ihs, Lee, Tsubota, and Gao offers a thorough understanding of the impact of pavement characteristics, specifically crack kinds, on the safety of roadways. The studies conducted by Ihs and Lee highlight the intricate connection between pavement integrity and traffic safety. Ihs's research reveals that ruts have a minimal impact on accident rates, while unevenness has a significant influence. Lee's analysis focuses on how poor pavement conditions affect crash severity differently depending on road speed and collision type. Tsubota's research contributes to the existing body of knowledge by establishing a correlation between pavement age and heightened accident hazards, hence emphasizing the significance of prompt maintenance. In conclusion, Gao's emphasis on airport pavements highlights the imperative requirement for timely identification and mitigation of cracks in order to uphold the safety of air travel. Collectively, these studies highlight the importance of implementing thorough and proactive pavement management plans that take into account multiple elements that impact road safety. This will ultimately lead to safer driving conditions and improved public safety.

4. Conclusion

The research conducted on pavement distress identification, with a specific emphasis on crack types, is crucial for ensuring road safety. The precision and effectiveness of crack detection and categorization have been greatly enhanced as a result of technological breakthroughs. Research has indicated the significance of precisely categorizing several types of cracks, including longitudinal, transverse, and alligator, in order to facilitate efficient road maintenance and mitigate the occurrence of accidents. Research that establishes a connection between pavement conditions and traffic safety emphasizes the impact of pavement integrity overall. This includes studies that examine crash severity and the relationship between pavement age and accident risks. In the future, it is anticipated that there will be more progress in crack detection techniques and their ability to adapt to various pavement conditions. This will play a significant role in the creation of safer road networks and the improvement of public safety.

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