Unsupervised Crack Segmentation and Detection using Graph Neural Network Clustering for Disaster Level Evaluation

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Background

- **Infrastructure Vulnerability**: According to the ASEAN Secretariat, the region has experienced over 1,000 disasters affecting 220 million people in the last decade.
- **Critical Need for Inspection**: Routine infrastructure inspection is essential for disaster risk reduction. The Asian Development Bank (ADB) reports that over 50% of infrastructure investments in the region are allocated for repair and maintenance.
- **Lack of Manual Resources**: Manual crack detection and disaster assessment are resource-intensive. A study by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) notes that the region faces challenges in terms of human resources for disaster risk management.
- **Advancements in Computer Vision**: Recent advancements in computer vision, particularly unsupervised crack segmentation, offer promise. These techniques can streamline infrastructure inspection, enhance scalability, and provide an automated way to assess disaster readiness.
- **Unsupervised Crack Segmentation**: Unsupervised crack segmentation techniques have gained importance as they offer cost-effective and scalable solutions for automatically identifying and assessing structural cracks in images without the need for manual annotation, addressing the labor-intensive nature of traditional methods.

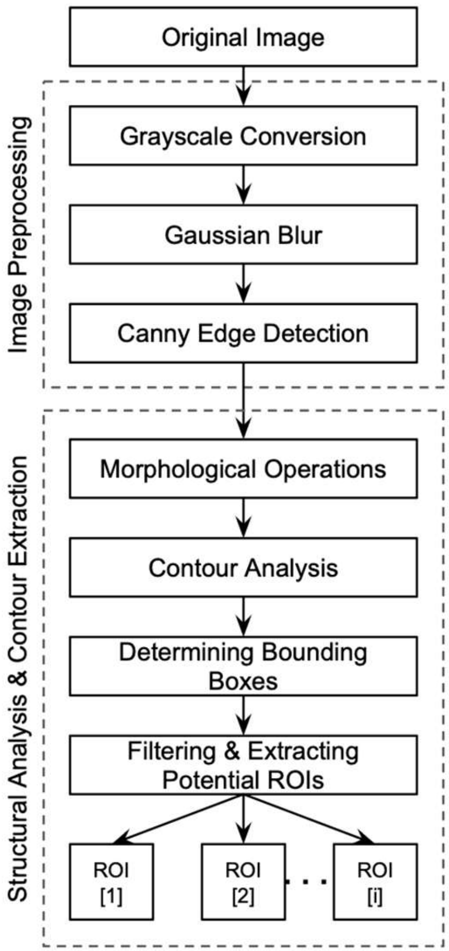
The main targets are:

1. **Automated Crack Detection and Segmentation**: This target aims to create a reliable system that can identify cracks in diverse types of infrastructure, including buildings and roads, without the need for manual labeling. Key aspects include (i) **precise crack detection**, (ii) **unsupervised learning**, and (iii) **real-time processing**.

2. **Disaster Level Assessment and Resilience Evaluation**: This target aims to provide insights into the potential impact of cracks on infrastructure and to prioritize mitigation efforts. Key aspects include (i) **severity categorization**, (ii) **disaster risk evaluation**, and (iii) **resilience enhancement**.

Challenges in Crack Segmentation

- Existing crack segmentation algorithms, including **DeepLabV3+**, **UNet**, **PSPNet**, and **ICNet**, have demonstrated remarkable performance in supervised settings.
- These algorithms leverage deep convolutional architectures and sophisticated post-processing techniques to achieve high segmentation accuracy when labeled training data are available.
- However, their effectiveness diminishes when faced with the **complexities of unsupervised scenarios**.
- Then, crack segmentation requires the ability to detect and outline cracks **without** the luxury of **annotated data**.
- This task is compounded by variations in **crack patterns**, diverse **lighting conditions**, and the presence of **image noise**.
- While these algorithms excel in supervised contexts, they fall short in addressing the nuanced challenges of unsupervised crack segmentation.
- This underscores the urgent need for innovative methodologies tailored to this challenging domain.



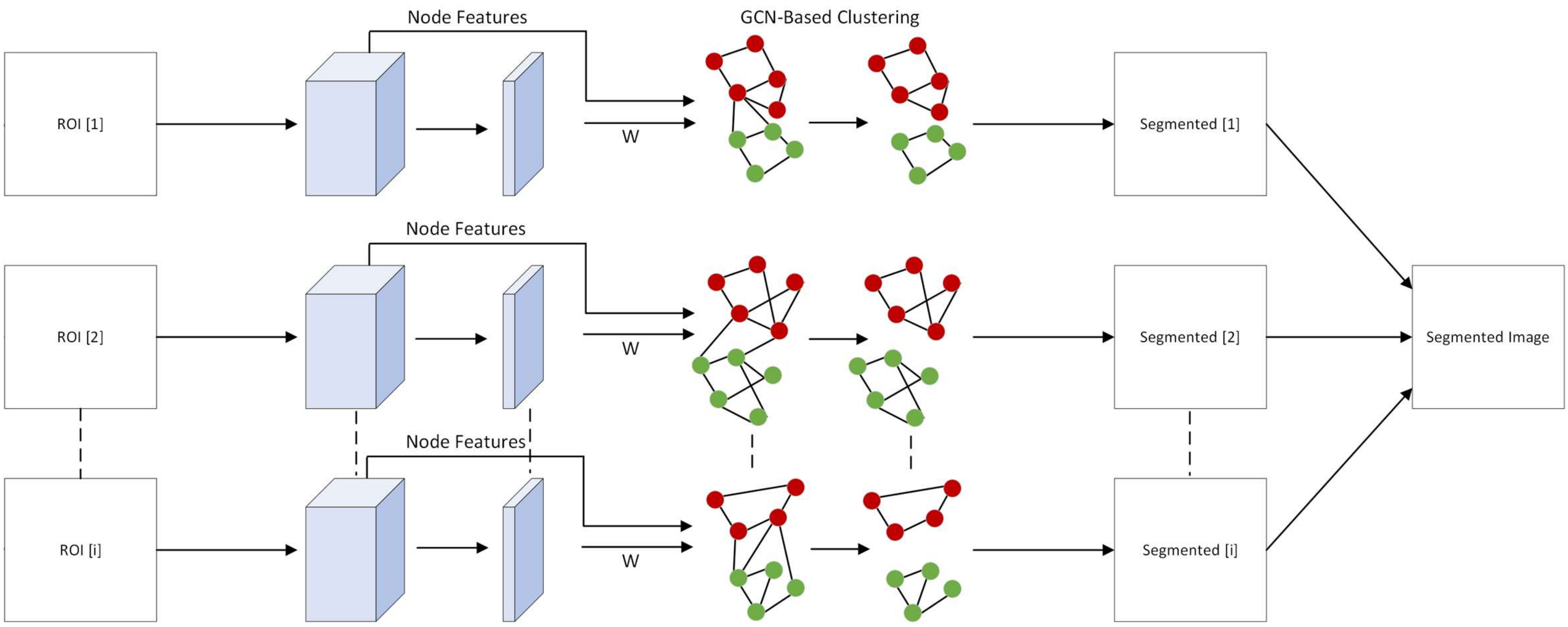
Part I. Candidate Crack Region Identification

The first part of our methodology is dedicated to **candidate crack region identification**. This phase is essential for precise identification of potential crack areas. As a part of our technological approach, we employ **Canny edge detection** and **morphological operations**. Canny edge detection is utilized to uncover edges and potential cracks, while customized morphological operations accentuate structural features. This integration reflects the scientific and technological aspects of our methodology, ensuring that candidate crack regions are identified accurately.

Part II. Crack Segmentation with Graph Neural Network Clustering

The second part of our methodology focuses on the actual crack segmentation. This stage includes the implementation of advanced technologies such as **Graph Neural Network (GNN) clustering**. We utilize **deep features** extracted through **Vision Transformer (ViT)** model to represent candidate crack regions as a graph. The GNN is then employed for clustering and segmentation.

Proposed Method



Unsupervised crack segmentation with graph neural network clustering

Experiments

We rigorously evaluate the performance of this part of the methodology through experiments with benchmark datasets like **CRACK500** and **GAPS384**. By comparing our results to established methods and assessing adaptability, we validate the practical applicability of our approach in real-world scenarios, such as structural health assessment.

Comparison results on CRACK500

Model	MIoU(%)	MAE	F1-Score(%)
UNet [12]	67.76	3.01	53
PSPNet [6]	62.88	2.81	50
ICNet [7]	56.15	2.77	39
DeepLabV3+ [3]	71.56	2.23	56
OpenCV	65.28	6.24	49
Ours	65.88	0.70	71

Test results on GAPS384

Model	MIoU(%)	MAE	F1-Score(%)
Ours	61.89	0.60	65

1. Scientific and Technological Perspective

Scientific Advancement - Our proposed method contributes to the scientific domain by pushing the boundaries of computer vision and image processing. It introduces advanced techniques, including Canny edge detection, morphological operations, and Graph Neural Network (GNN) clustering, to tackle the complex challenge of unsupervised crack segmentation. This scientific progress fosters innovation in image analysis and data-driven structural health assessment.

Technological Innovation - From a technological perspective, our method represents a significant leap in automated crack detection and segmentation. By integrating Vision Transformer (ViT) models and GNNs, it leverages cutting-edge technologies to process complex images and identify potential structural issues. This technological advancement has the potential to revolutionize infrastructure maintenance practices.

2. **Societal Perspective**

Enhanced Infrastructure Safety - The societal impact of our method is profound. By enabling automated and accurate crack detection, it contributes to the safety of infrastructure in Thailand, the ASEAN region, and even Japan. Identifying structural issues early can prevent disasters, protect lives, and ensure the longevity of vital structures.

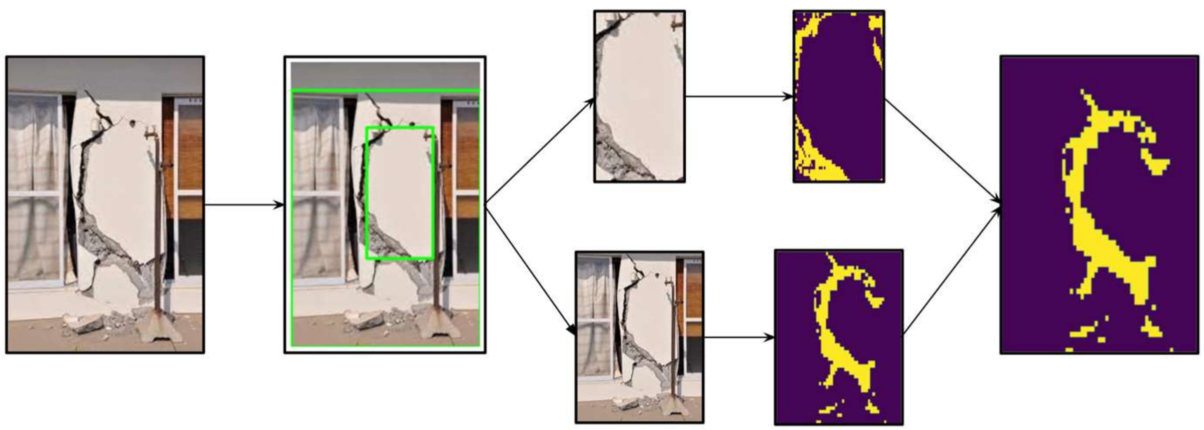
Efficiency and Cost Savings - Our approach enhances societal well-being by optimizing infrastructure maintenance. It reduces the need for manual inspections and accelerates the identification of potential problems. This efficiency not only saves costs but also minimizes disruptions in everyday life.

3. Collaborative Perspective

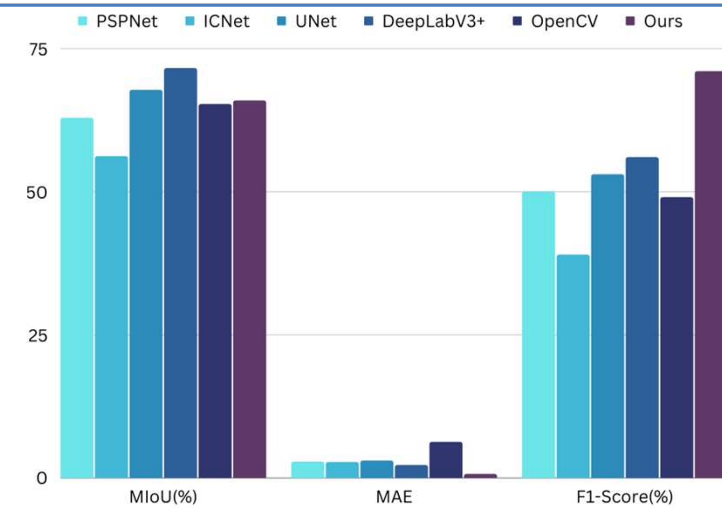
Regional Collaboration - In a broader perspective, our method fosters collaboration among ASEAN nations and beyond. The shared goal of infrastructure safety and disaster mitigation drives collaborative research and implementation efforts. By sharing knowledge and best practices, the region collectively benefits.

Global Relevance - Our approach aligns with the global trend of leveraging technology for infrastructure resilience. Collaborative initiatives with Japan, known for its advanced infrastructure technologies, can further enhance the applicability of our method on a global scale.

Output/Outcome



Regions of interest extraction and GCN-based segmentation



Comparative test results on CRACK500 dataset

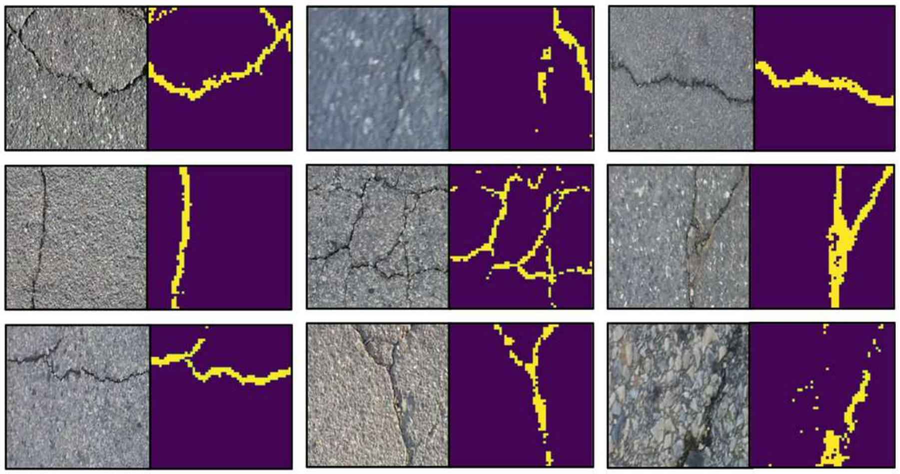
Segmented Crack Images: The method will provide segmented images where cracks are accurately delineated, aiding in visual identification of structural issues.

Severity Assessment: The severity levels of detected cracks will be determined, allowing for categorization into high, moderate, or low severity, indicating the potential impact on infrastructure.

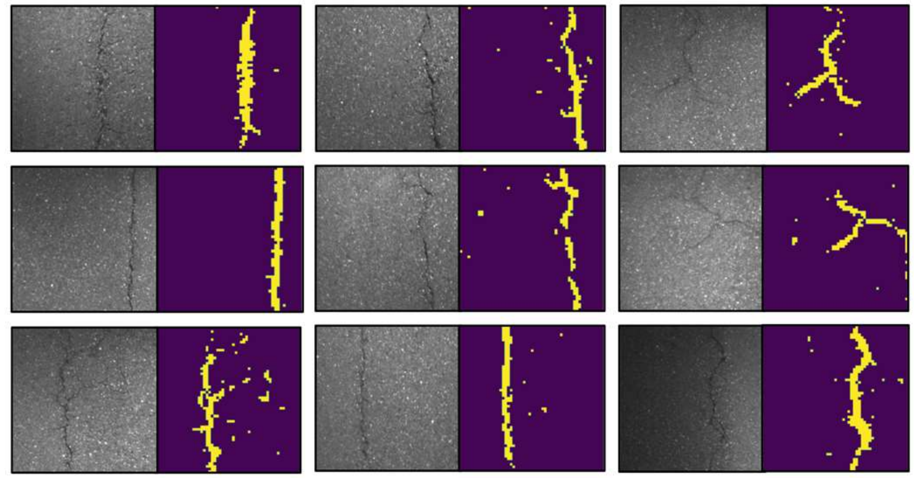
Adaptability to Diverse Datasets: The method will demonstrate its adaptability by producing consistent results across diverse datasets, showcasing its robustness.

Real-time Detection: The implementation of the methodology will allow for real-time detection and assessment of structural cracks, facilitating prompt action.

Output/Outcome



Results examples on CRACK500 dataset



Results examples on GAPS384 dataset

Disaster Preparedness: The method contributes to disaster preparedness by evaluating the vulnerability of cracked infrastructure to natural disasters, allowing for proactive mitigation.

Global Applicability: The methodology's success can pave the way for its adoption in other regions and countries facing similar infrastructure challenges, contributing to global infrastructure safety.

Advancements in Computer Vision: The method advances the field of computer vision by introducing innovative techniques for complex image analysis, which can have broader applications beyond structural health assessment.

Future Research Endeavors

Delving Deeper into Feature Relationships: Future research will explore inter-feature relationships to enhance the accuracy of object detection, including structural crack segmentation.

Addressing Sample Imbalance: Efforts will be made to develop adaptive weighting mechanisms to address sample imbalance challenges in expansive point cloud scenes.

Plan for Connected Projects

Crack Quantification for Disaster Level Evaluation: A critical connected project involves developing a framework for quantifying the severity of cracks detected. This initiative aims to assess the impact of cracks on infrastructure and disaster resilience, with the ultimate goal of enhancing disaster level evaluation.

The journey continues towards safer and more resilient infrastructure.

Key Takeaways:

- Our proposed method introduces a comprehensive approach for unsupervised crack segmentation and disaster level evaluation.
- Scientific and technological advancements include Canny edge detection, morphological operations, and Graph Neural Network clustering.
- Societal benefits encompass enhanced infrastructure safety, cost savings, and efficiency in maintenance.
- Collaboration opportunities extend to regional and global levels, addressing shared challenges in structural health assessment.
- The method offers outputs such as segmented crack images and severity assessments, with outcomes including improved structural health assessment and disaster preparedness.
- The potential impact of our approach transcends borders, contributing to infrastructure resilience on a global scale.

Thank You for Your Attention!