Cascaded Workflow of Automated Pavement Crack Detection and Quantification Using Segmentation AI Models

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Abstract

This research aims to develop a two-stage framework for the automated detection and quantification of cracks on asphalt and concrete pavements using pavement surface imagery. To overcome the limitations of traditional edge-extraction methods, the proposed approach enhances the identification of fine and thin cracks. In the first stage, the cracking is located within 2D/3D vehicle-captured images using bounding boxes generated by either human experts or predictive models such as a vision-language model developed in our prior study. The second stage utilizes high-resolution segmentation AI models to delineate crack boundaries and extract geometric features (width, length, and area), facilitating severity scoring according to distress identification guidelines and pavement management standards specified by different highway transportation agencies. We evaluate several state-of-the-art architectures, including YOLOv26, SCSegamba (a structure-aware vision mamba network), and Dichotomous Image Segmentation (DIS), by training and testing them on a new dataset of 1,432 pavement images. A morphological method is then applied to quantify the lengths and widths of cracks. Results indicate that this cascaded framework significantly improves detection accuracy and shape capturing for subtle surface cracks, providing a more quantifiable method for automated pavement condition assessment.

Introduction

1. Prepared dataset

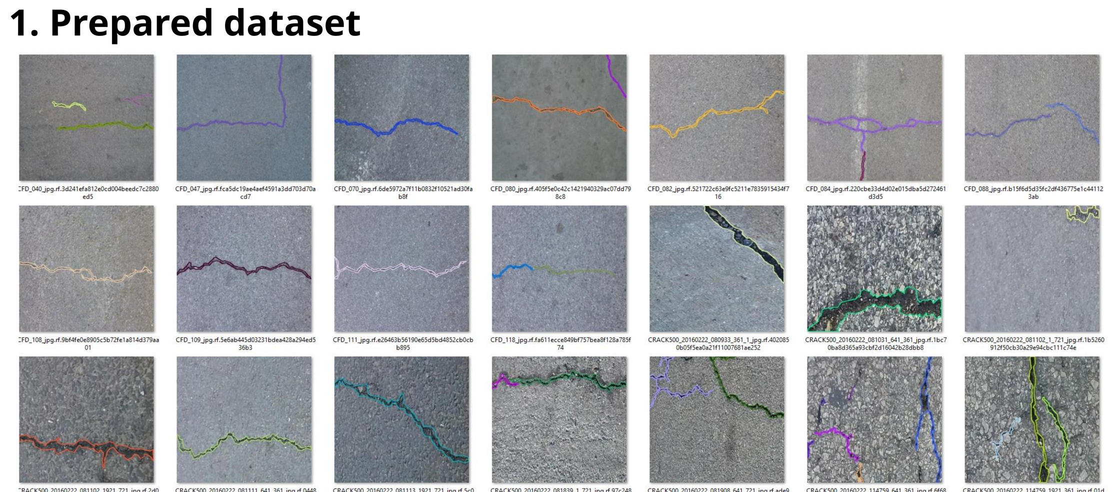
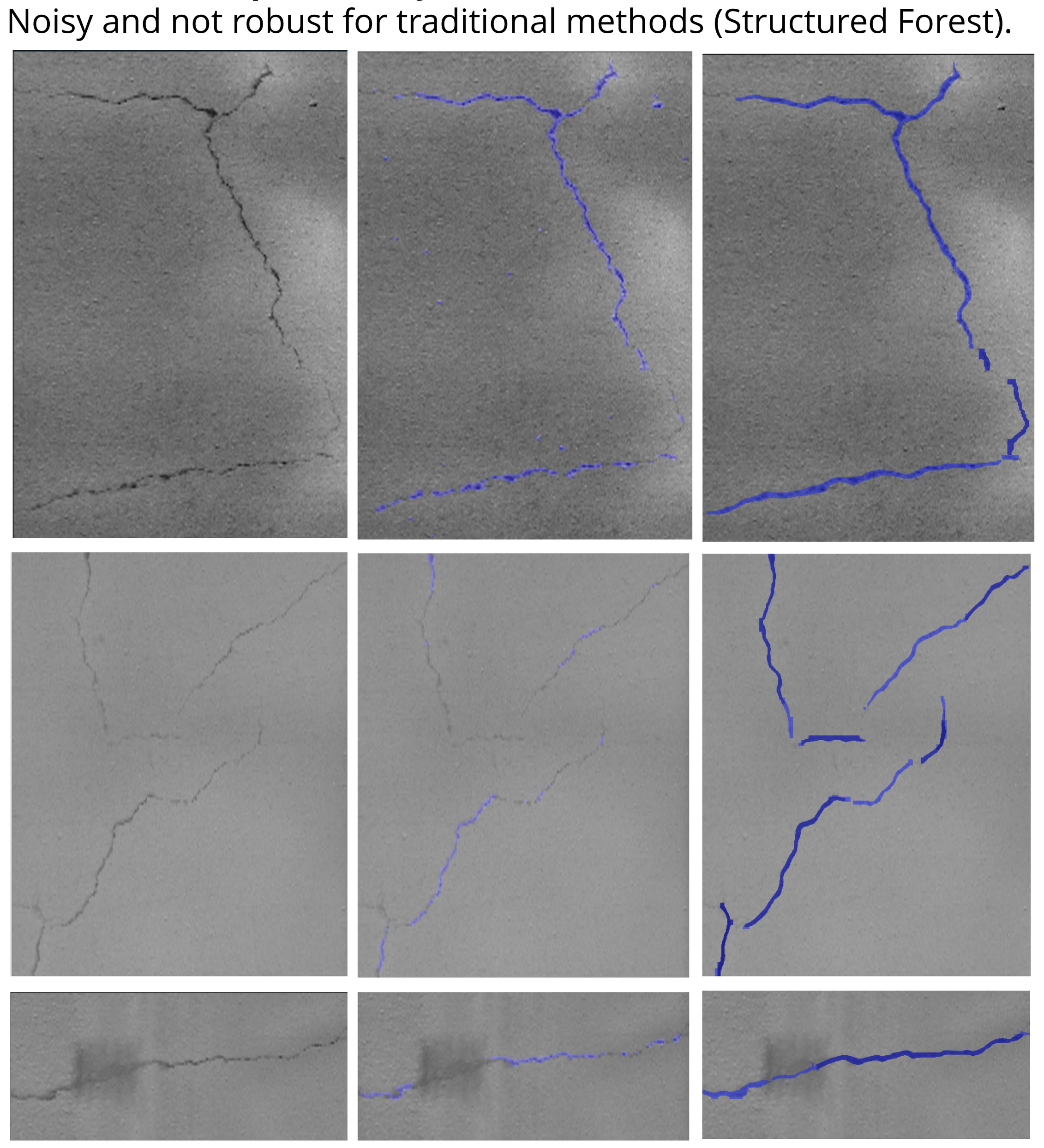


Figure 1 Examples of training data with overlaid masks on original images.

2. Problems in prior study

Noisy and not robust for traditional methods (Structured Forest).



(a) Original (b) Structured Forest (c) YOLOv26-seg

Figure 2 Crack segmentation from Structured Forest and YOLOv26-seg.

Methodology

1. Cascaded workflow with segmentation neural network

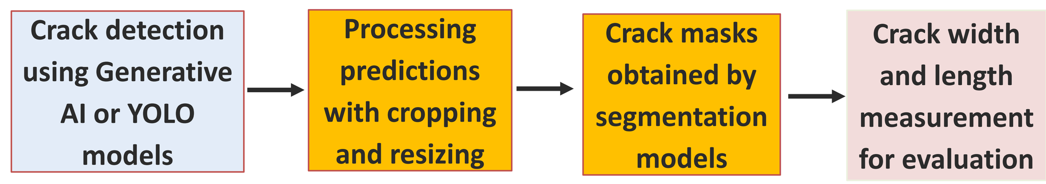


Figure 3 Flowchart of using crack detection and measurement models for pavement crack quantification.

2. Distress detection and cropped with YOLO models

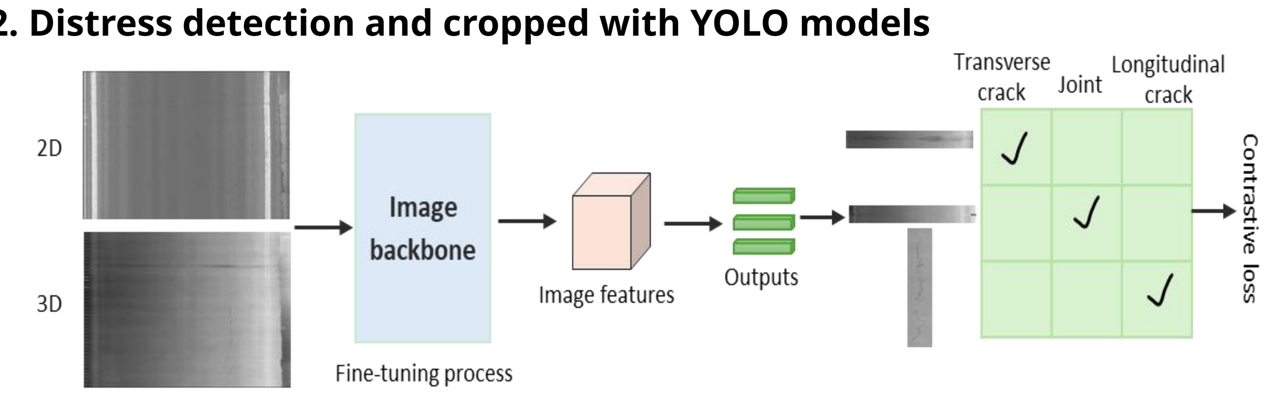


Figure 4 YOLO Models for pavement distress detection.

3. Segmentation models

1) YOLOv26-seg

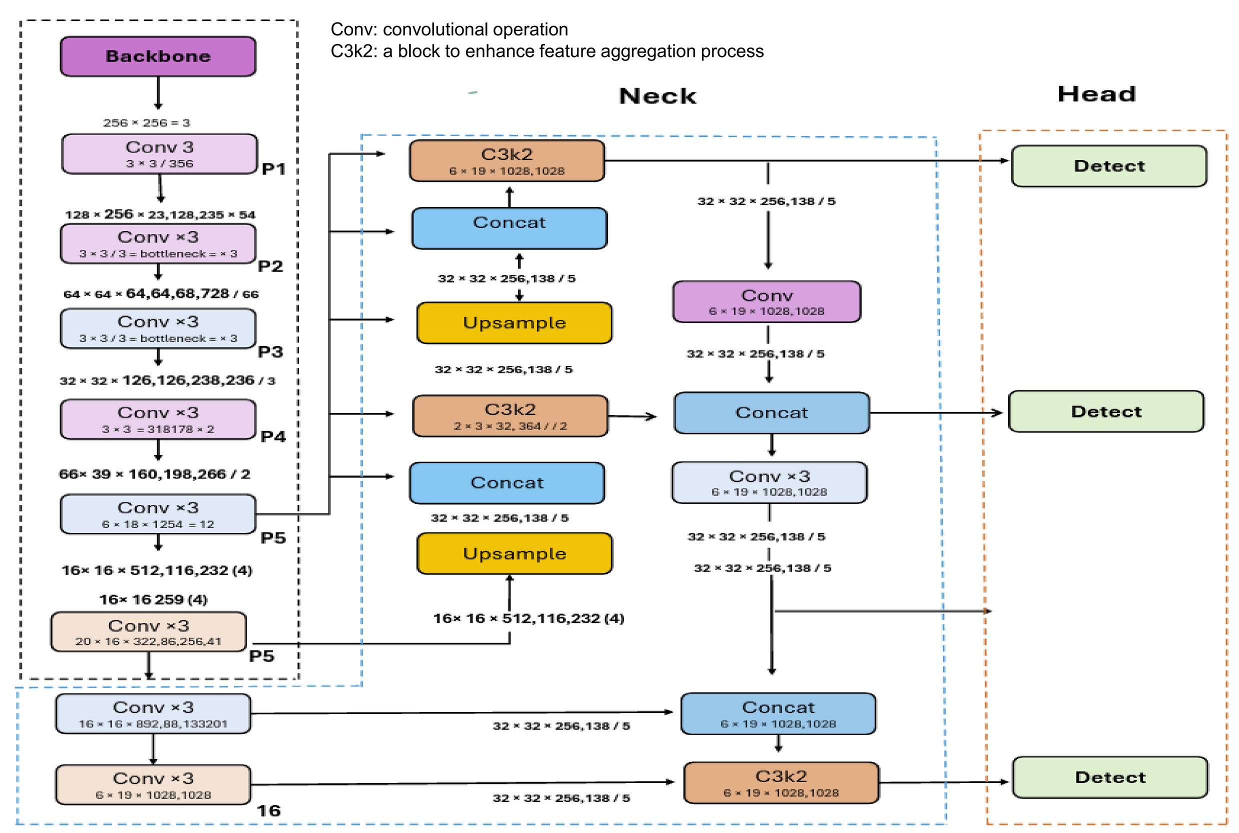
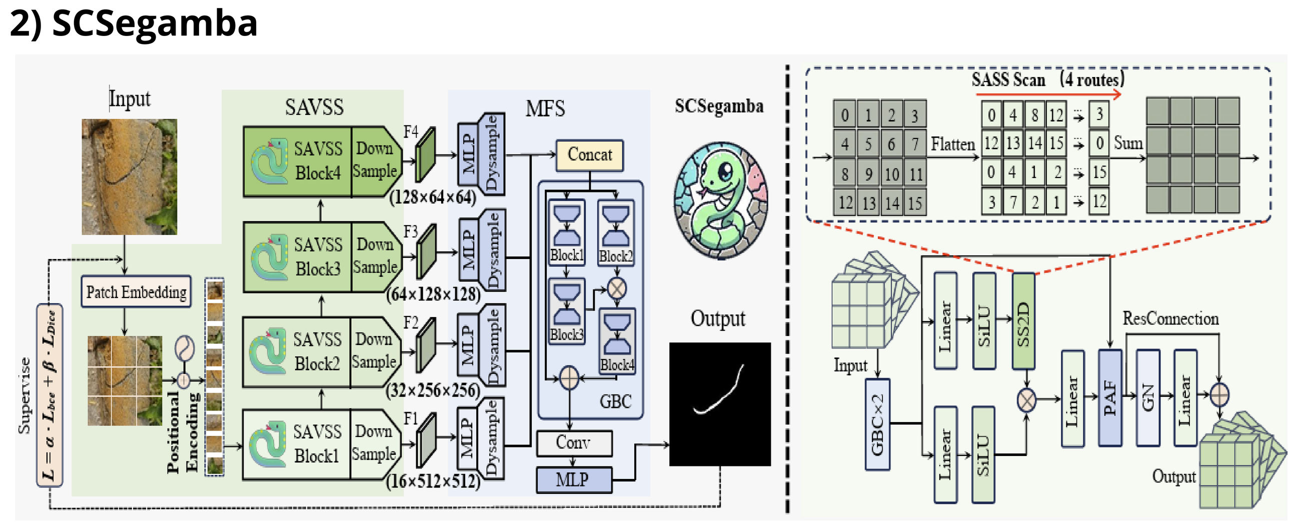


Figure 5 Framework of YOLOv26 for object detection and segmentation algorithm.

2) SCSegamba



(a) Network architecture of SCSegamba (b) Architecture of SAVSS block

Figure 6 Overview of the SCSegamba.

3) Dichotomous Image Segmentation (DIS)

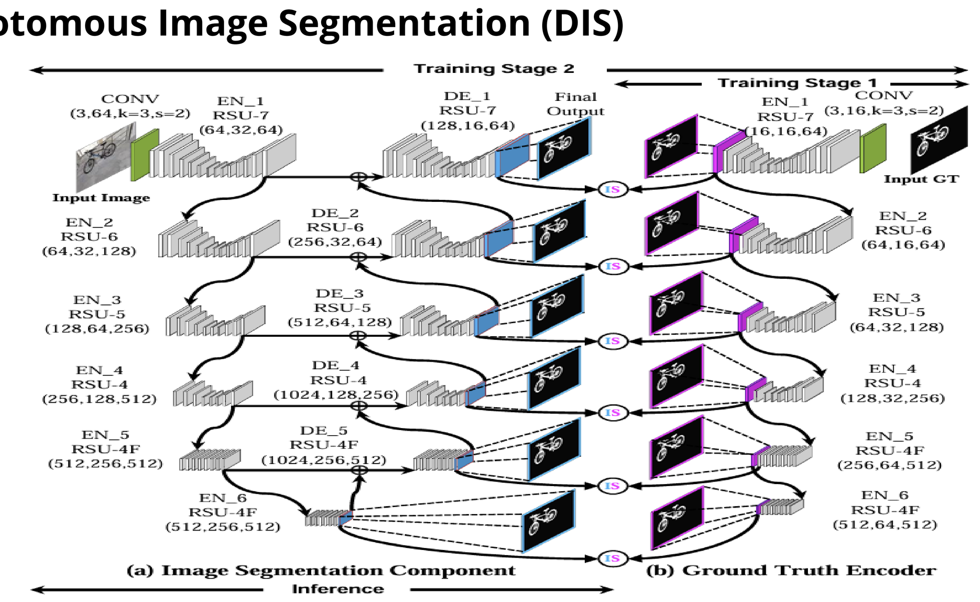


Figure 7 Proposed IS (intermediate supervision)-Net baseline.

4. Crack measurements

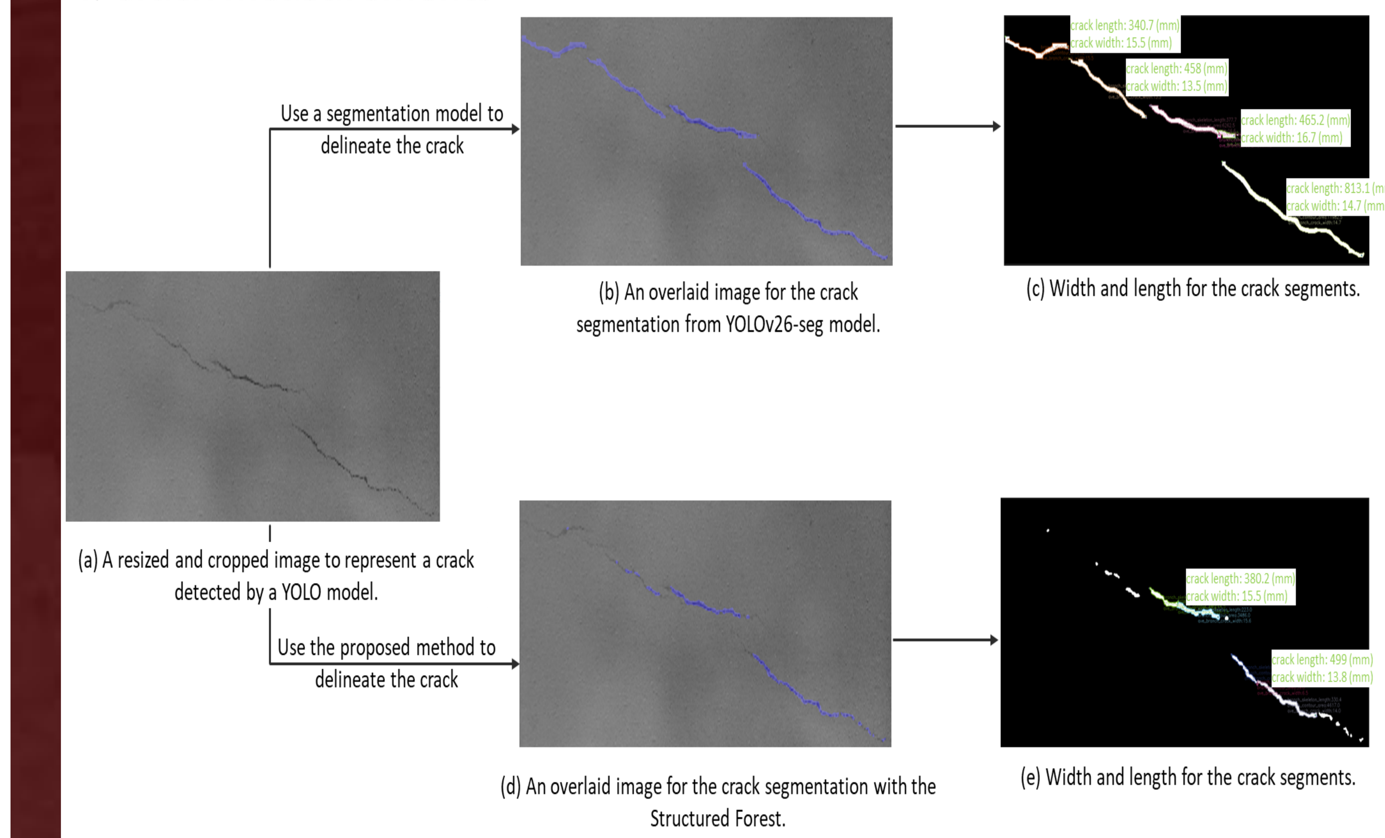


Figure 8 Crack measurements using segmentation model (e.g., YOLOv26-seg) and Structured Forest on a cropped image.

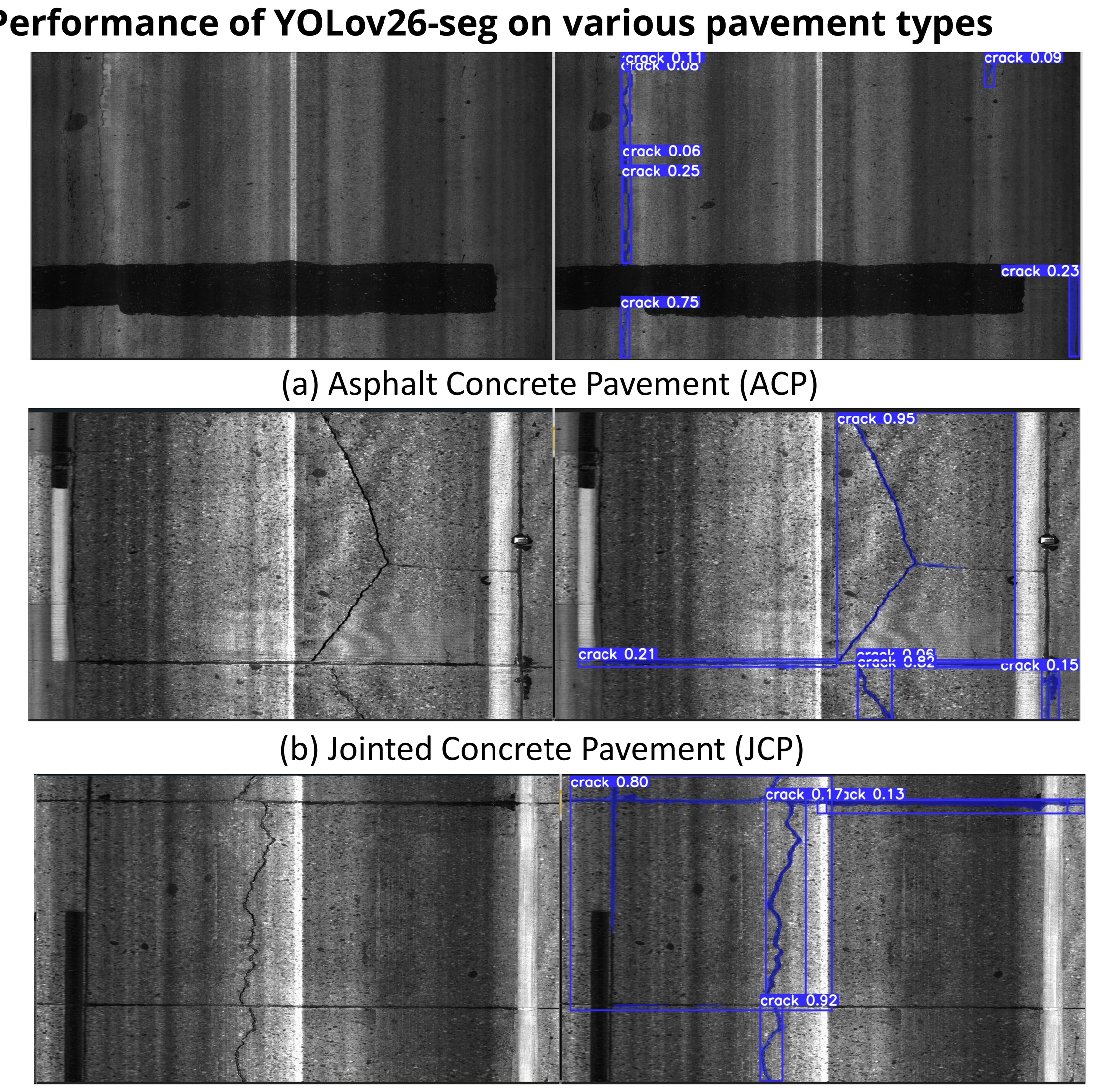
Results

1. Metrics for segmentation models

Table 1. Precision, recall, and F1 score for the segmentation models

Segmentation models	Precision	Recall	F1 score
YOLOv26-seg	0.699	0.559	0.621
SCSegamba	0.822	0.773	0.797
DIS	0.986	0.864	0.921

2. Performance of YOLov26-seg on various pavement types



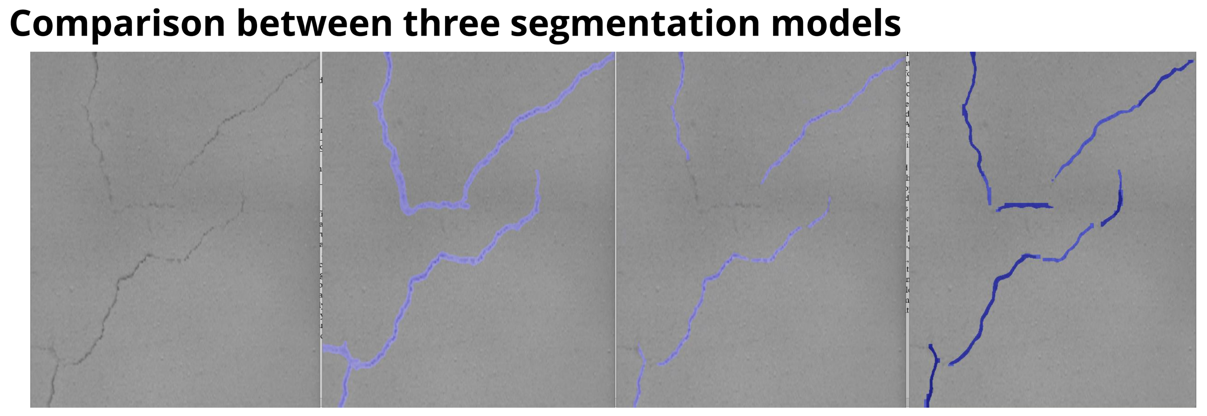
(a) Asphalt Concrete Pavement (ACP)

(b) Jointed Concrete Pavement (JCP)

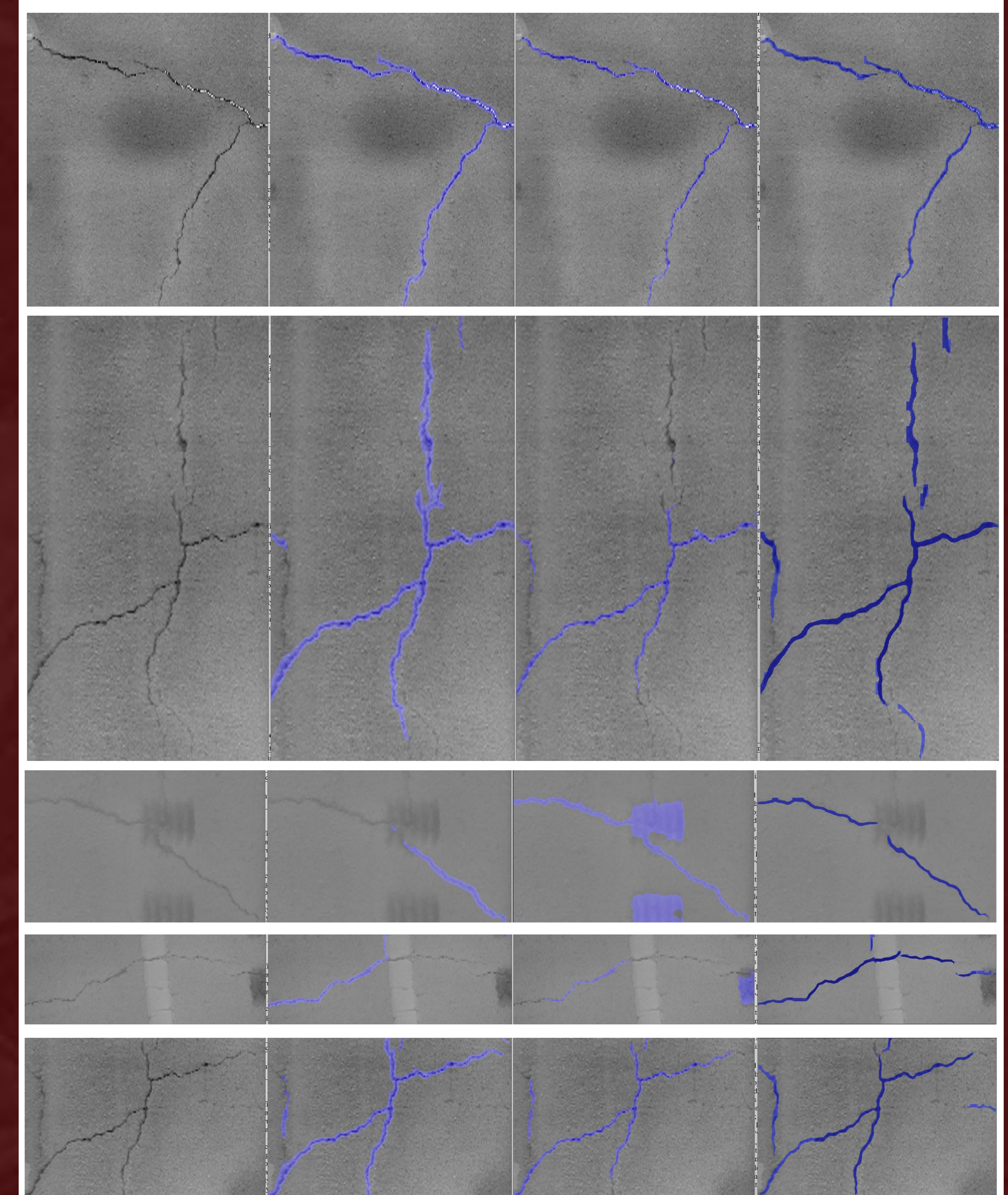
(c) Continuously Reinforced Concrete Pavement (CRCP)

Figure 9 Crack masking with YOLOv26-seg model on different pavement types.

3. Comparison between three segmentation models



(a) Original (b) DIS (c) SCSegamba (d) YOLOv26-seg



(a) Original (b) DIS (c) SCSegamba (d) YOLOv26-seg

Figure 10 Examples for crack segmentation by three DIS, SCSegamba, and YOLOv26-seg.

4. Observation

1) Although DIS and SCSegamba perform better than YOLOv26-seg on the validation dataset, the test on real-word data shows the latter is more accurate to delineate the cracks.

2) YOLOv26-seg is more robust for crack segmentation on noisy images.

Conclusions

Several findings are observed through this research:

1) Segmentation models outperform the traditional image processing method (Structured Forest) to delineate cracks on pavements, especially when this method fails to capture the edges of thin or fading cracks.

2) YOLOv26-seg is the best model to segment cracks on both 2D or 3D images. It also works well on JCP and CRCP.

3) The proposed crack measurement framework with segmentation models shows a good agreement with the prior method.

4) In the future, large-scale experiments will be conducted for the proposed method.

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