Deep Learning System for Automated Cracking Survey & Its Performance with Pixel Accuracy: CrackNet

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Supported by FAA, FHWA, several DOTs, and Users Worldwide

2017-11-16, Denver Marriott West, Road Profiler Users Group (RPUG)

Challenges of Cracking Automation

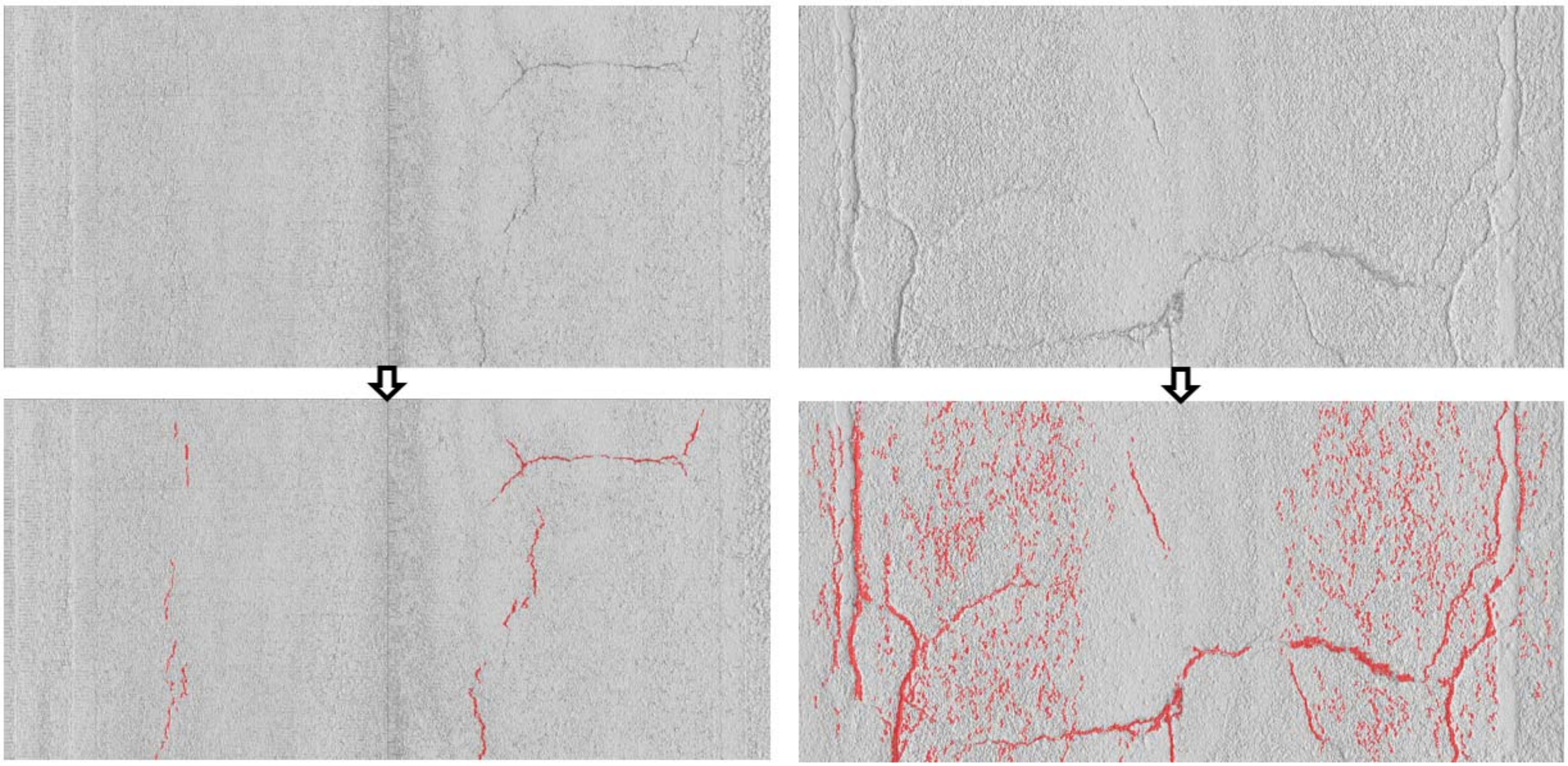
- Complexity
  - Pavement Surface: A Highly Complicated Environment with Extensive Uncertainties & Variations on Surface Condition
  - Distress Identification: Challenging Even for Well-Trained Human Operators
  - Diverse Pavement Surface Texture: Open-Graded
  - Presence of Non-Cracking Pavement Distresses

Limitations of Traditional Algorithms

- Simple Methodology & Specific Assumptions
- Not Fully Validated on Diverse Pavement Surfaces
- Limited or No Learning Capabilities
- Inconsistent Precision & Bias Levels on Different Roads

Common Failures

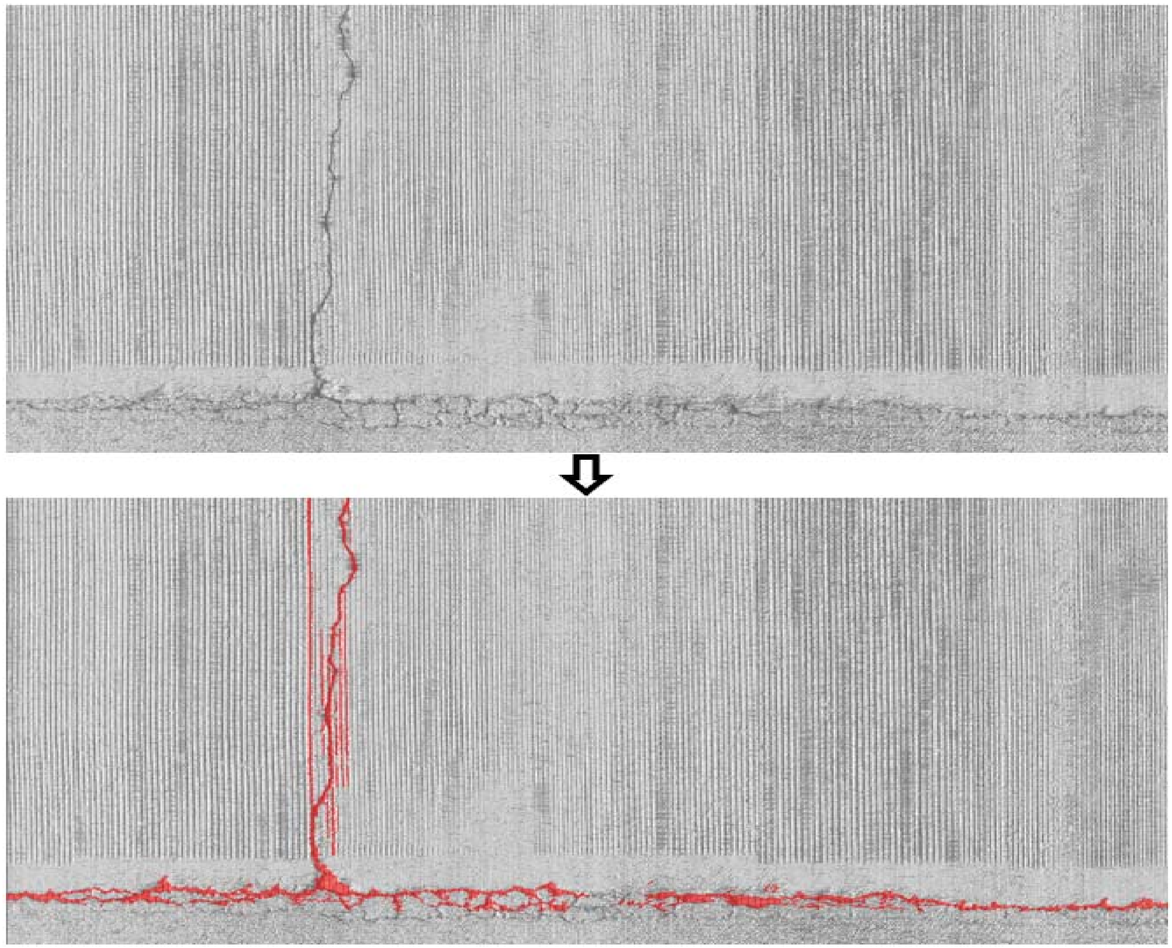
- Inconsistent Accuracies for Pavement with Various Texture
- Requirement of Substantial Human Intervention and Manual Processing



Smooth Pavement Surface — Highly Textured Pavement Surface

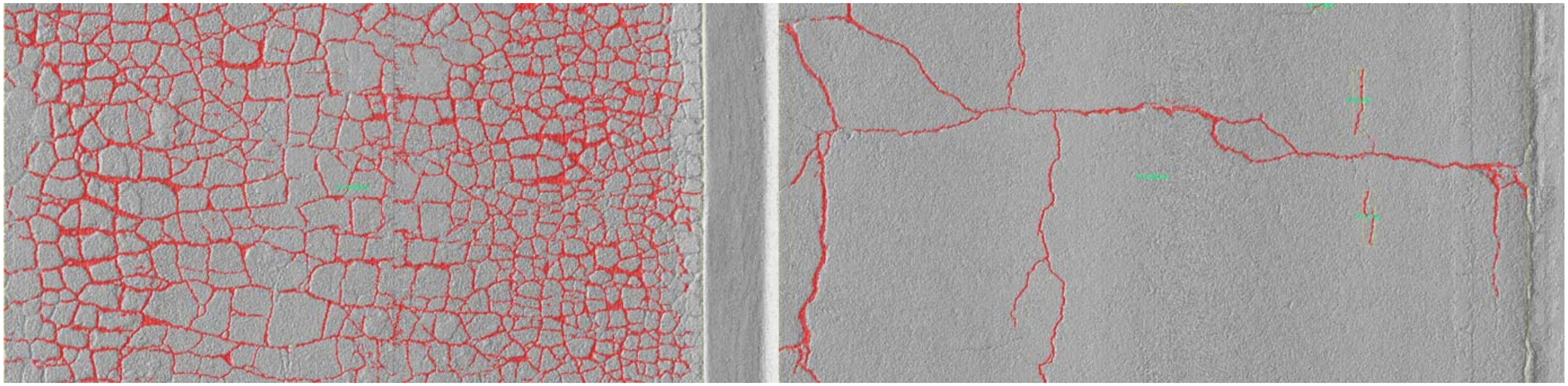
Common Failures

- Interference from Other Patterns

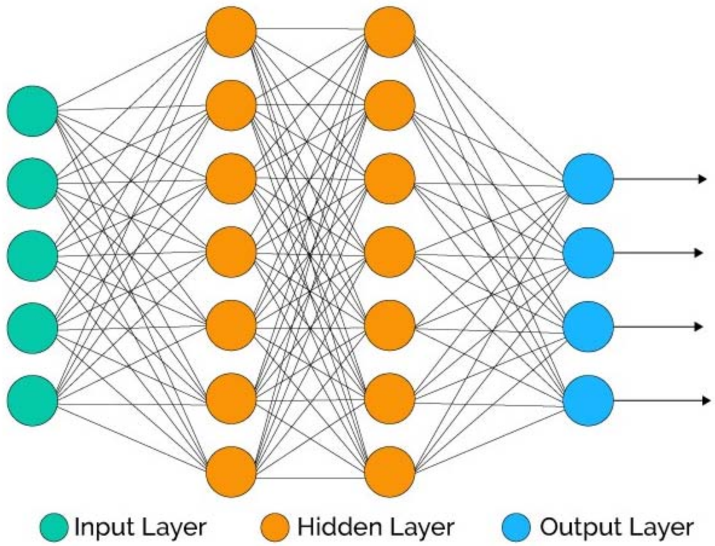


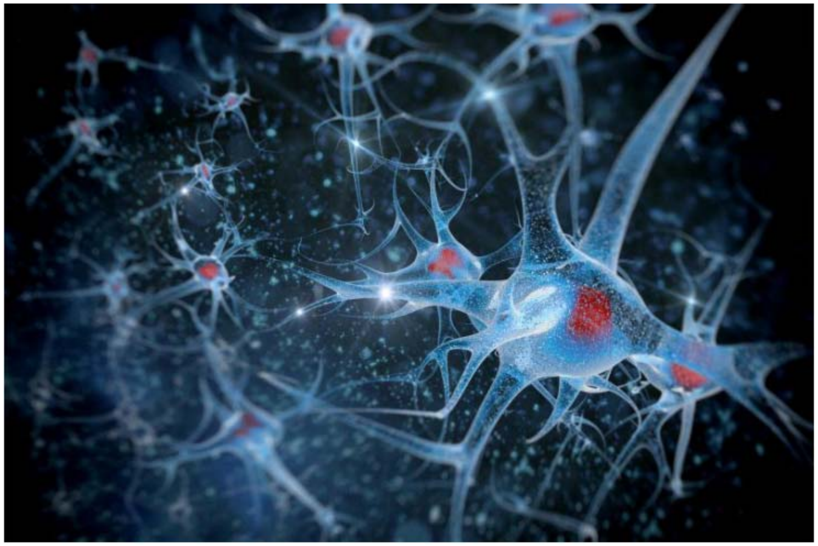
Ultimate Objectives for True Automation

- Cracking with Pixel-Perfect Accuracy for Any Pavements
- Crack Classification: Label Distress Types
- No Human Intervention in Production with Acceptable and Consistent Precision & Bias Levels for Any Pavements
- Real-Time Processing in a Single Workstation
- Meeting New Protocol Requirements



Traditional Artificial Neuron Network (ANN)





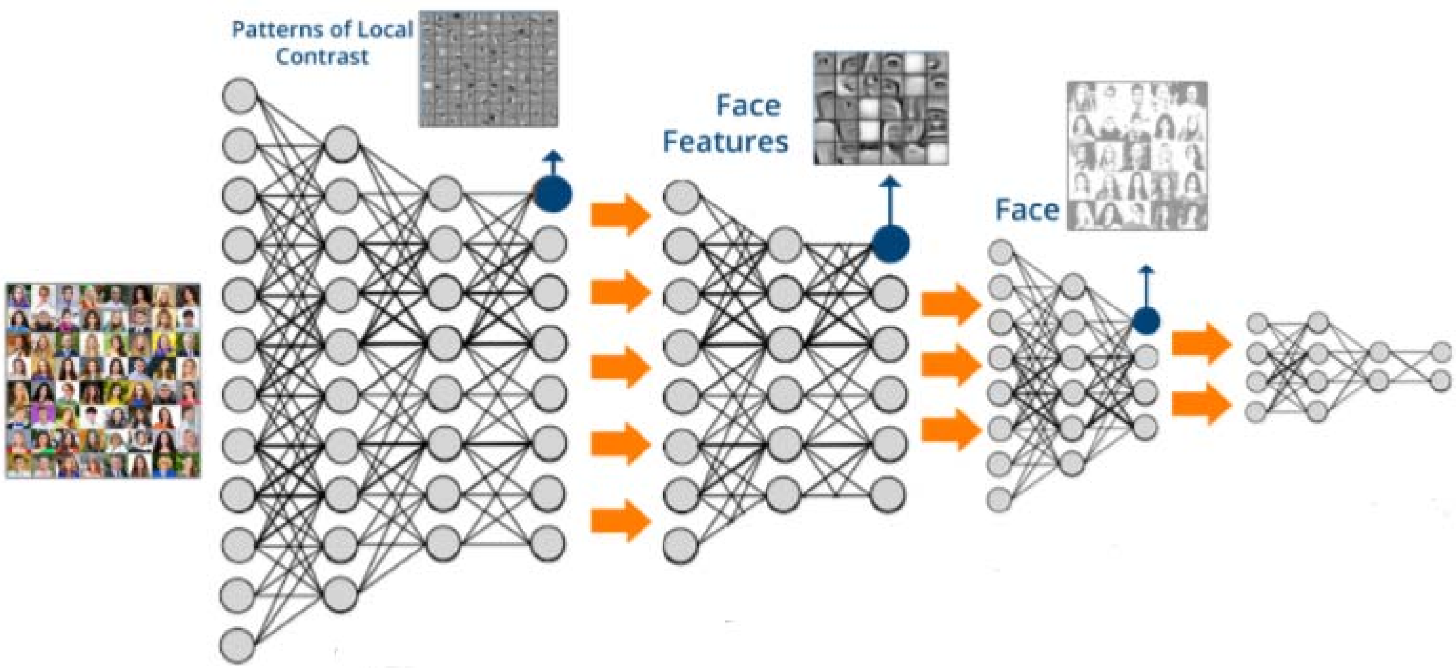
# of Neurons<10^4

# of Neurons=10^{11} (Human Brain)

- Shallow Abstraction
  - Limited Number of Layers & Neurons
  - Cannot Fully Reflect the Complexity of Problems
- Limited Amount of Data

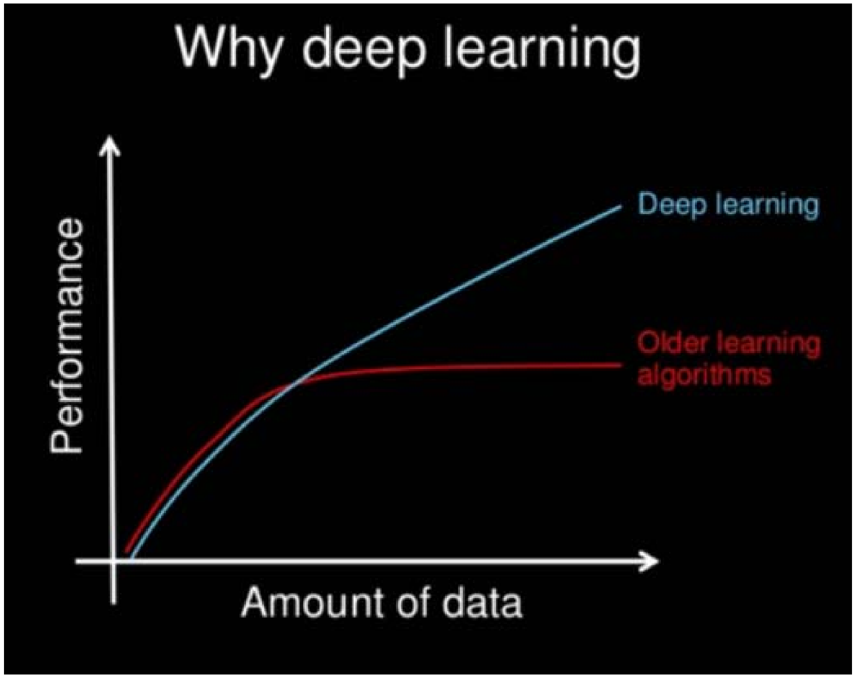
Deep Learning: New Generation of ANN

- Deep Abstraction: # of Layers: 10^1-10^3, for Complex Problems
- Complex Connections Among Neurons: 10^2-10^4 per Neuron
- Enhanced Reliability: Exhaustive Variations of Example Data
- High-Performance Processing: **Critical**

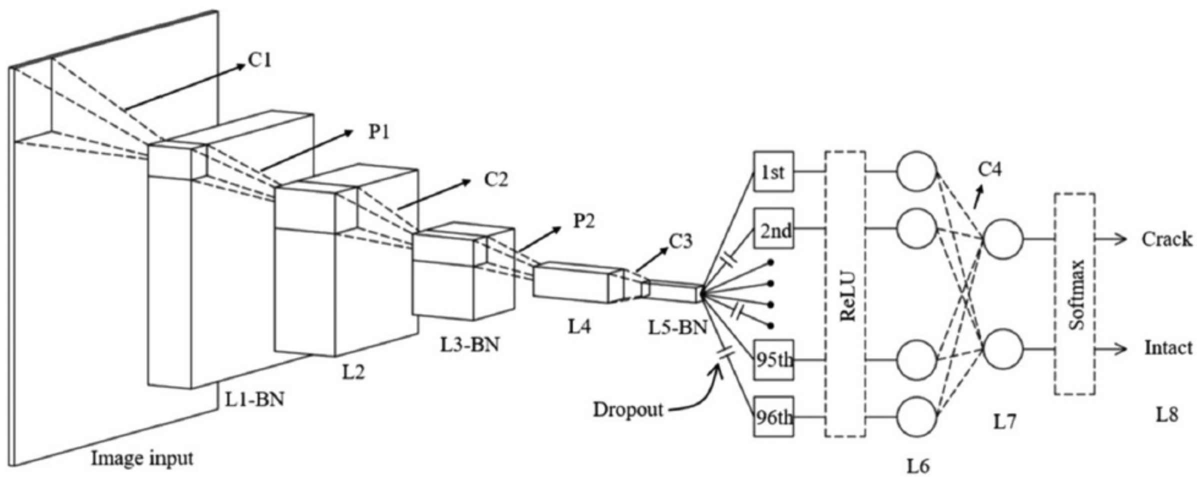


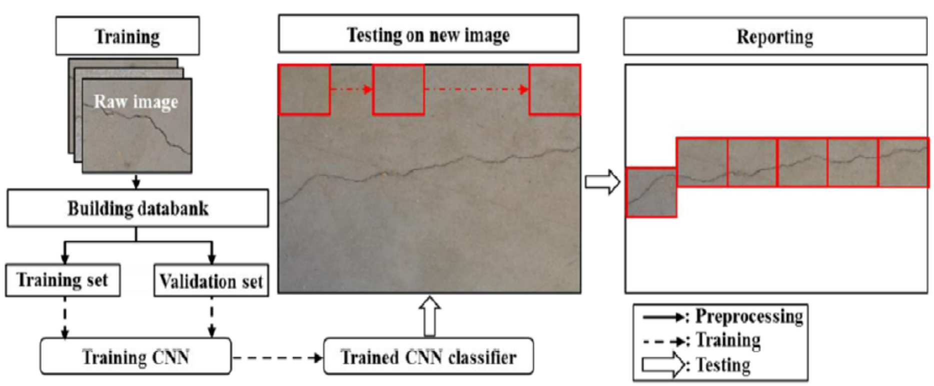
Why Deep Learning?

- Strong Learning Ability and Versatility
  - A DL Network: Multiple Types of Objects (Pavement Distresses)
- Enhanced Reliability
  - Feed with Exhaustive Variations of Examples
- Learning/Knowledge Accumulation
  - Similar to Human Learning Process



CNNs for Cracking Detection (Cell Image)





- Detect Cracks in Image Cells
- Training Data are limited (550 images)
- Lack of Pixel-Perfect Accuracy

***Deep Learning-Based Cracking Damage Detection Using CNNs**, Computer-Aided Civil and Infrastructure Engineering, 2017*

DL System Design for Cracking (Pixel Based)

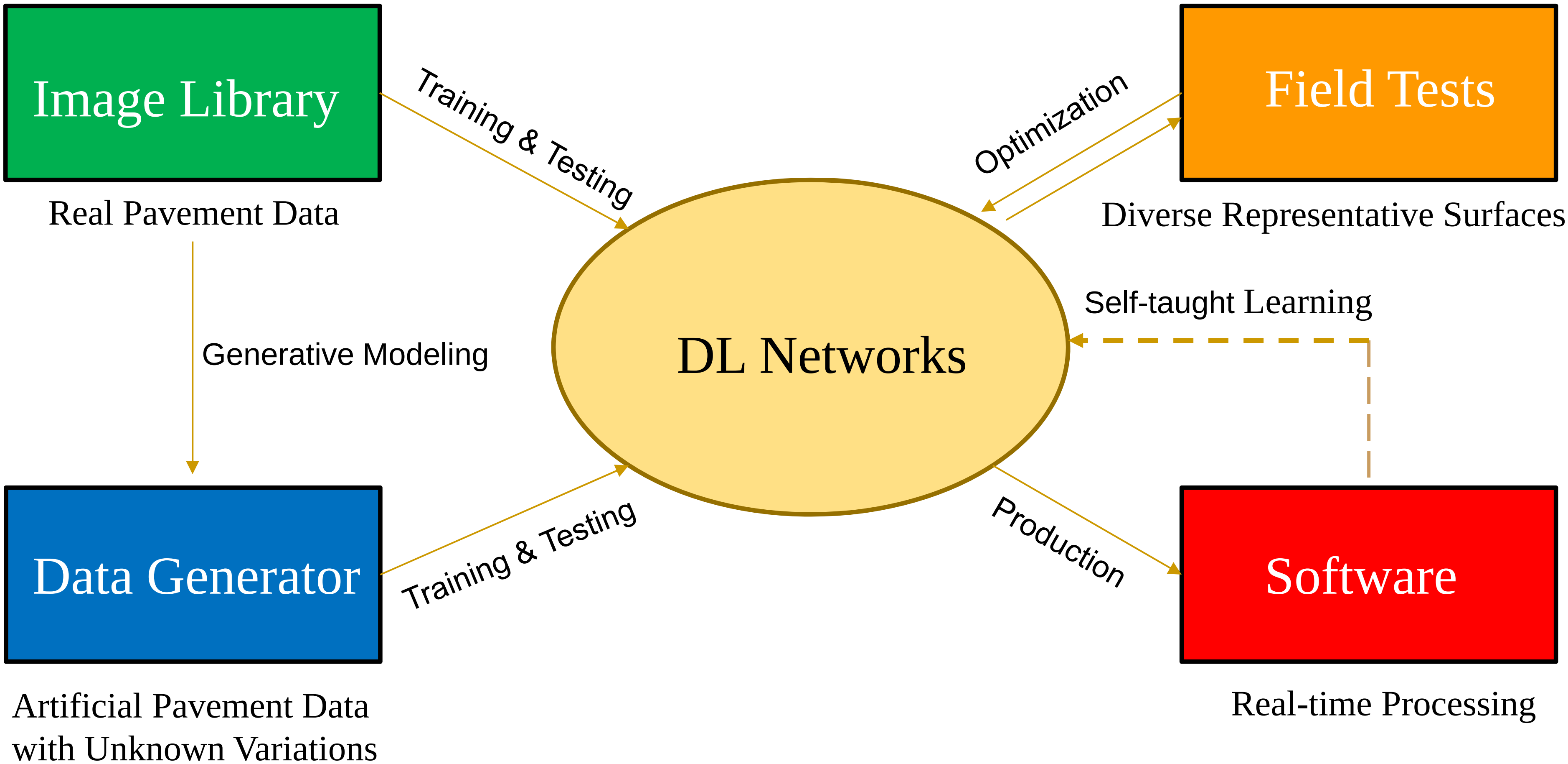
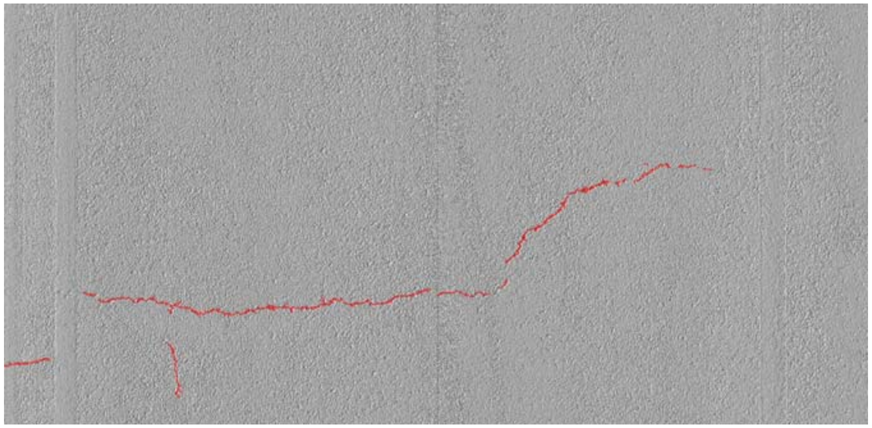
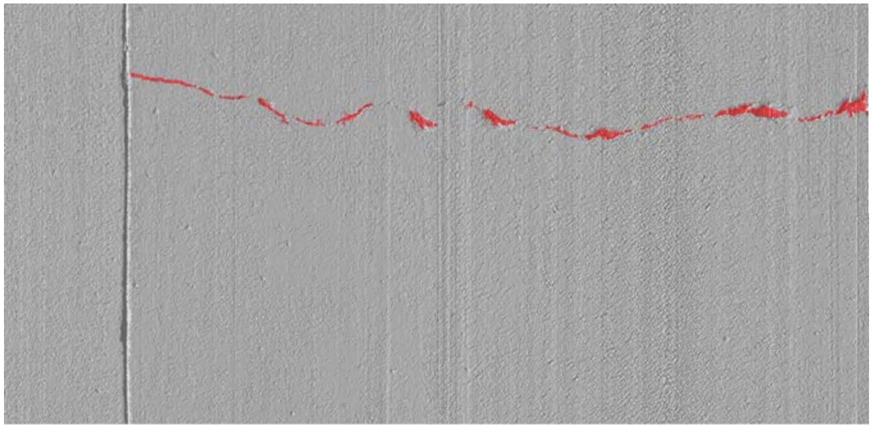


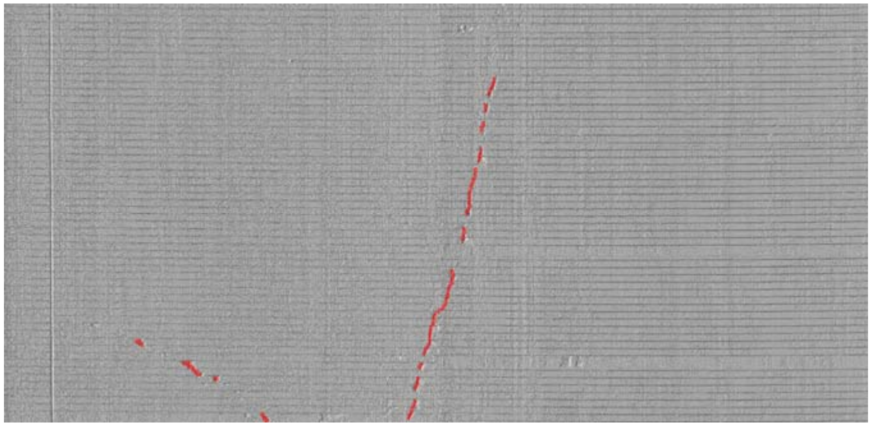
Image Library

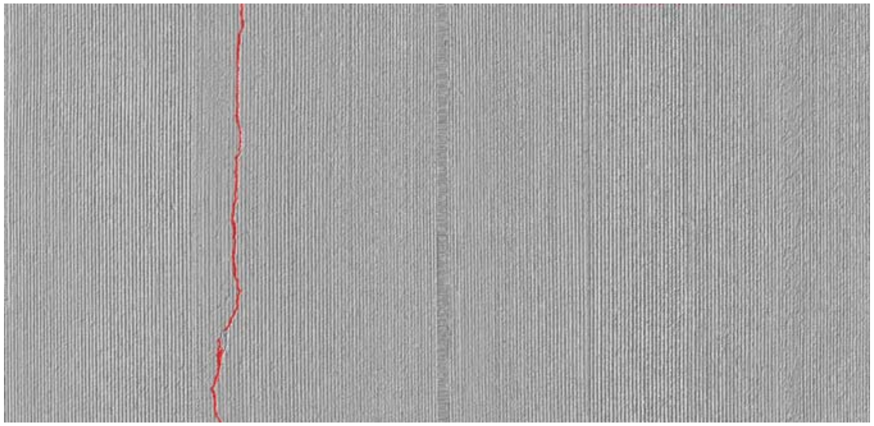
- Source Data Type
  - 3D Data & 2D Images
- Image Library Size
  - 2016-2017: 10,000 3D Images + 10,000 2D Images
  - 2017-2020: 50,000 3D Images + 50,000 2D Images
- Ground Truth with Pixel-Perfect Accuracy
  - Manually Marked, Verified; **Automated/Augmentation**
- Diversity
  - All Typical Variations of Pavement Distresses

Typical Labeled Examples of Image Library



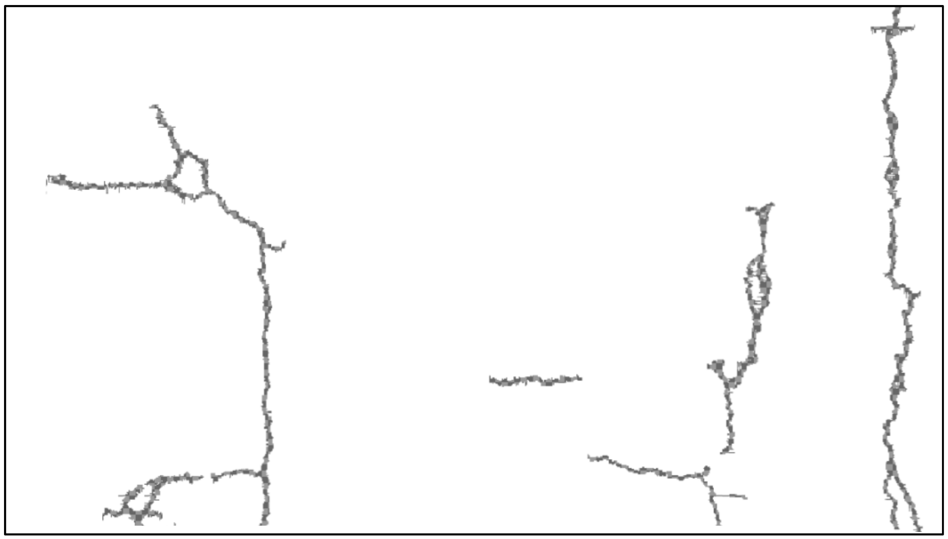




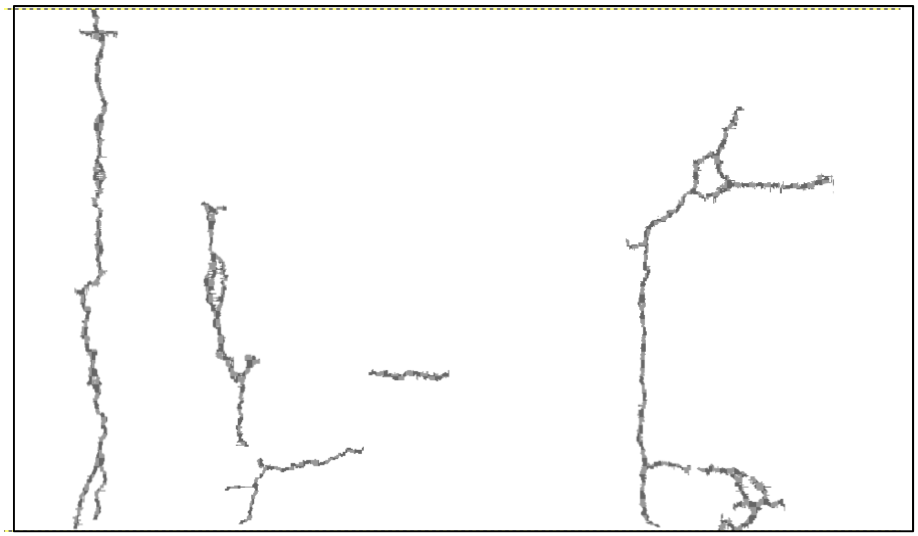


Data Augmentation for More Training Data

- Generate Ground Truth by Manually Labelling
- Randomly Apply Rotation, Translation and Scaling to Generate More Training Data
- Even Better then Manually Labeled Data: 100% Correct

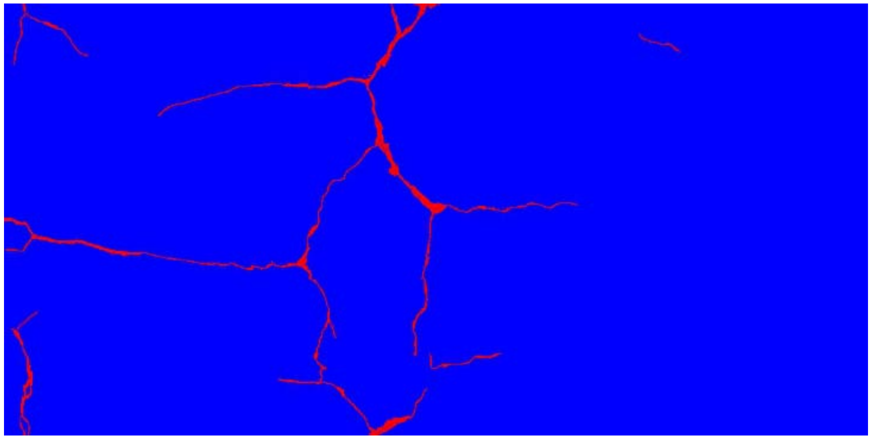


Manually Labeled Cracks

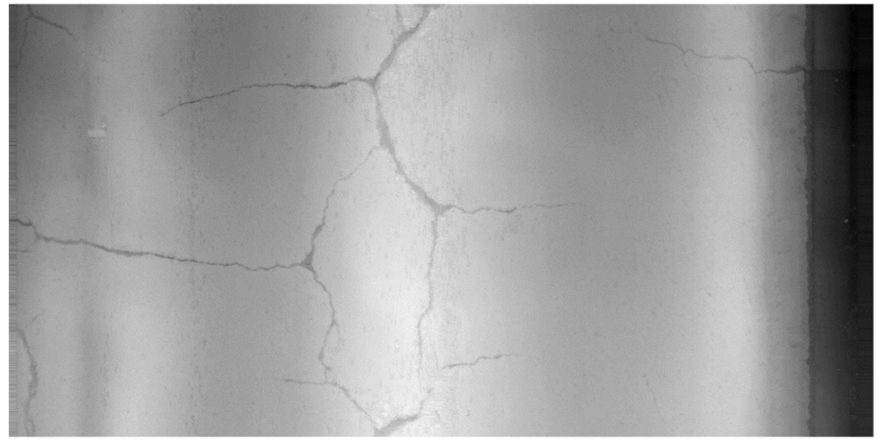


Augmented Data

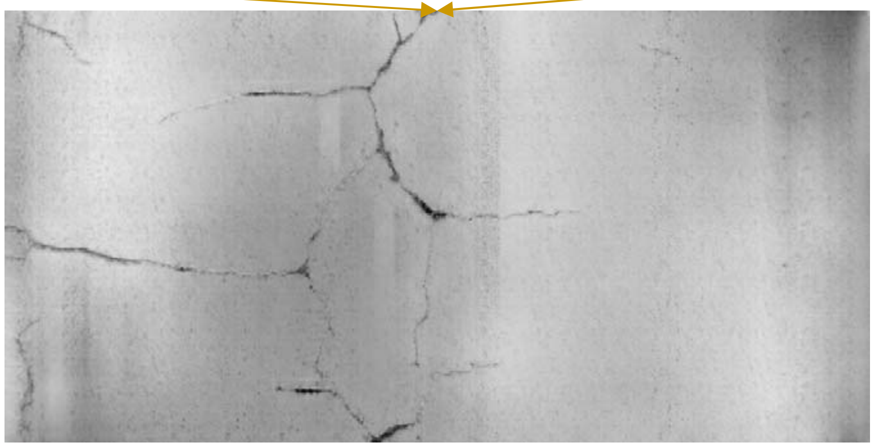
Data Augmentation via Generative Models



Label

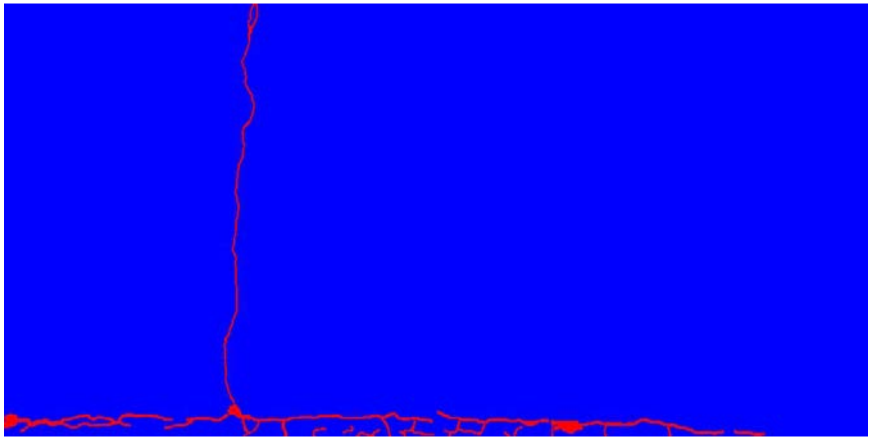


Original Image

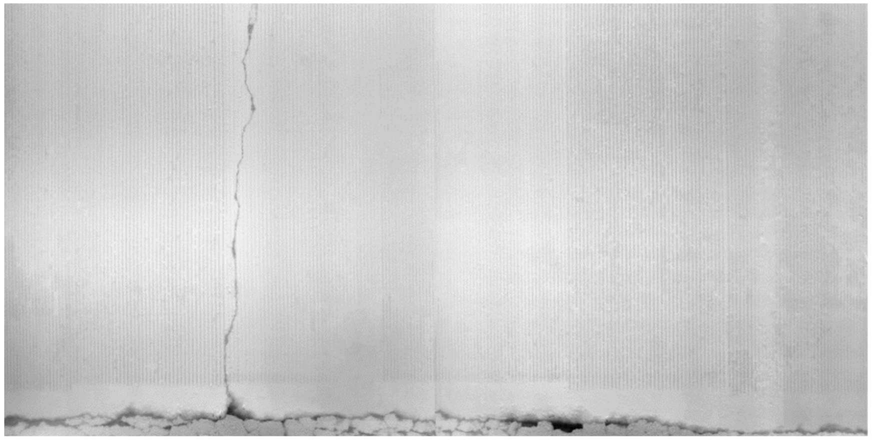


Artificial Image Generated via Generative Adversarial Networks (GAN)

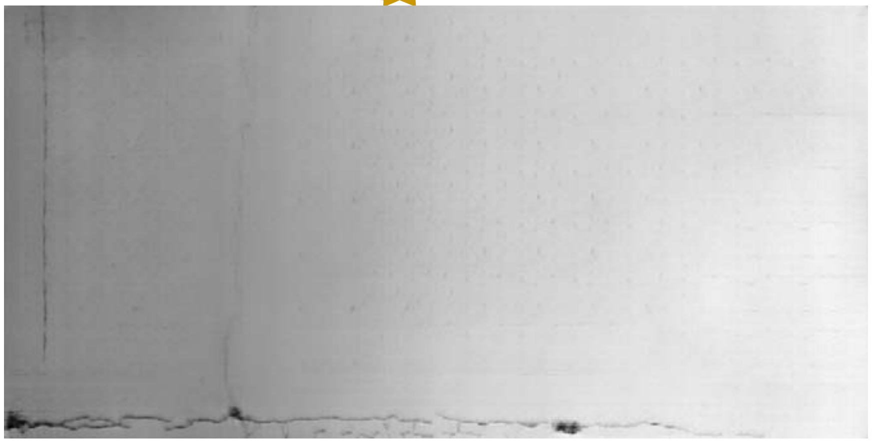
Data Augmentation via Generative Models



Label



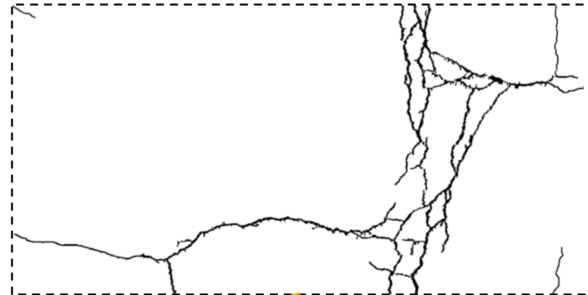
Original Image



Artificial Image Generated via Generative Adversarial Networks (GAN)

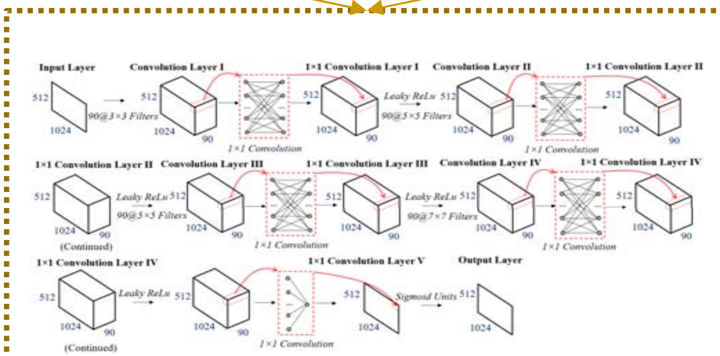
Deep Learning Net (Pixel Based): CrackNet

Input Image

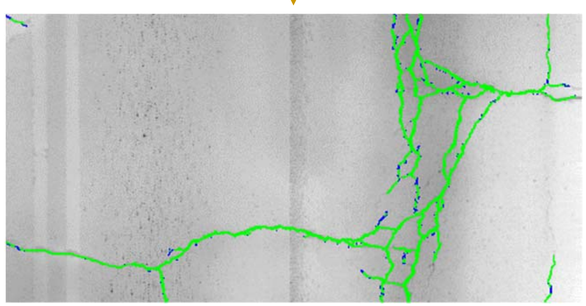


Ground Truth with
Pixel-Perfect Accuracy

DL Network

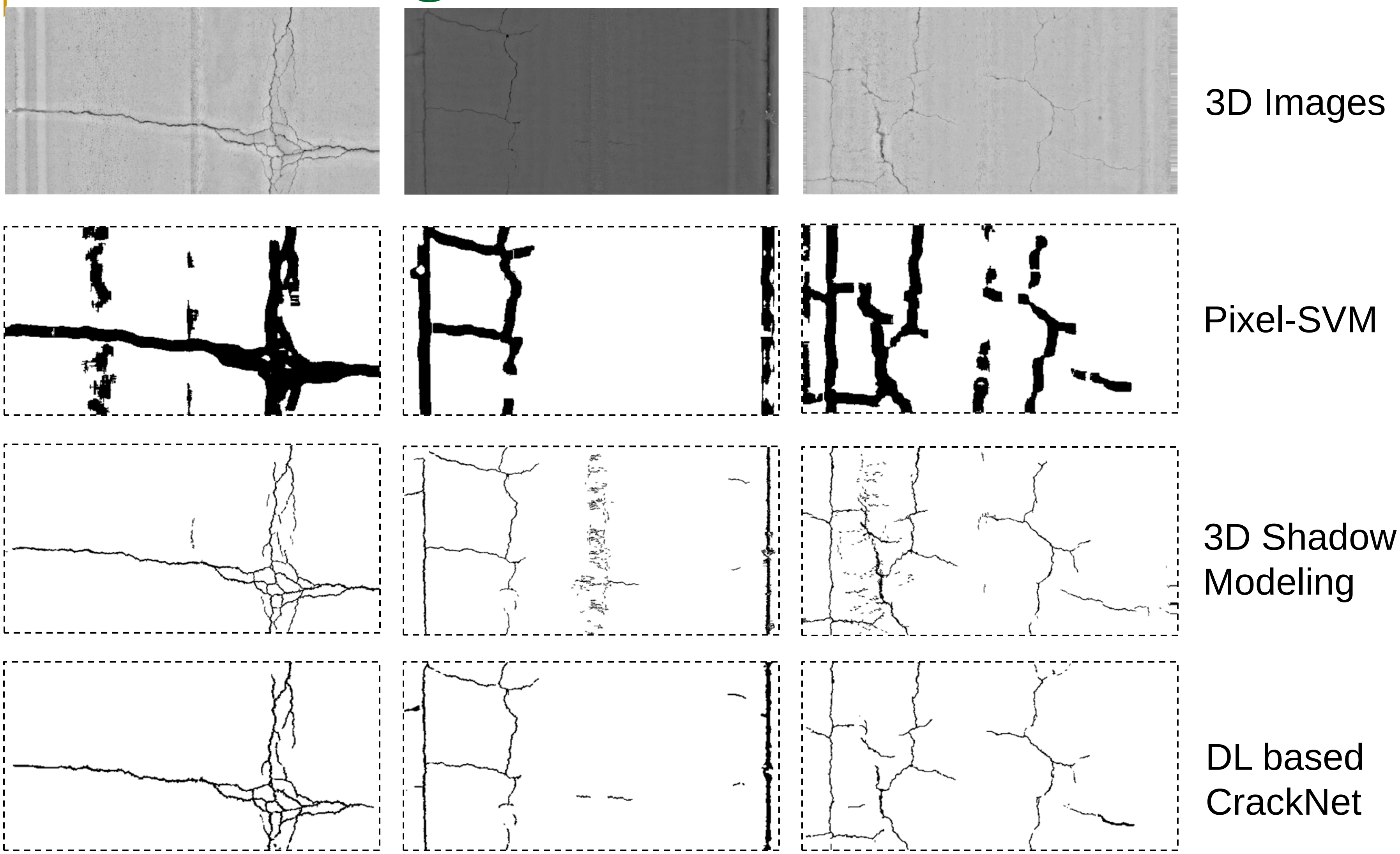


Recursive Training

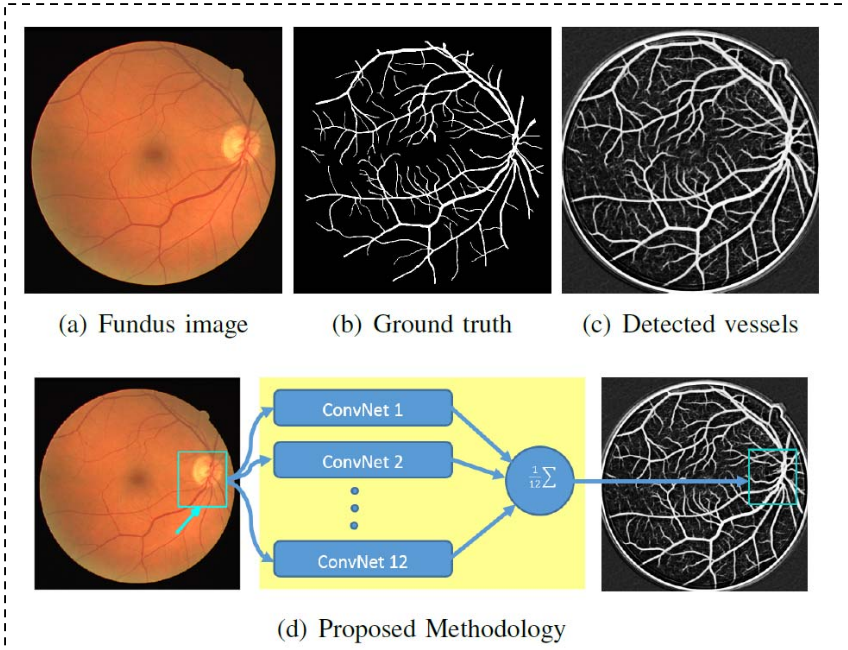


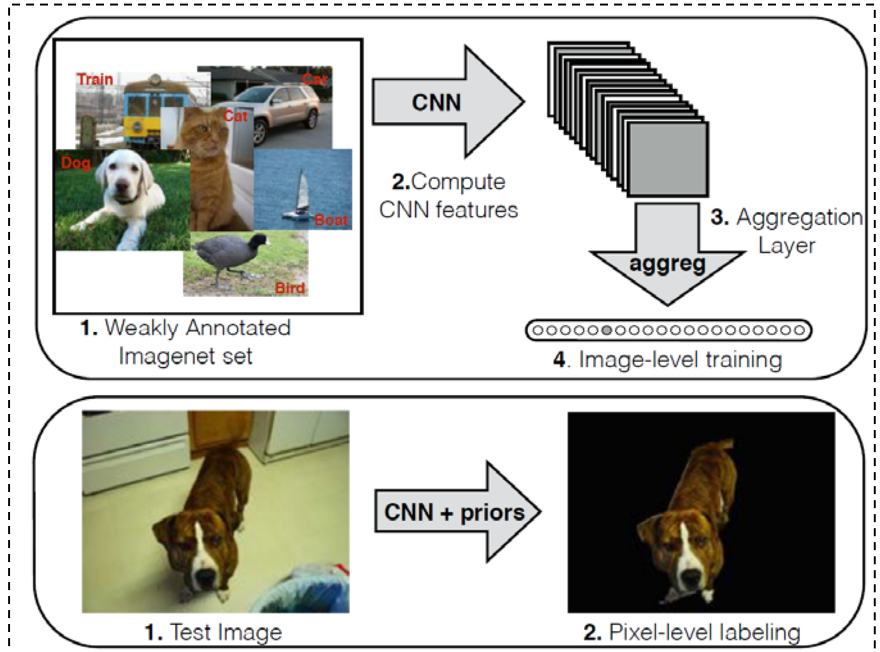
Detection Output
with Pixel-Level
Accuracy

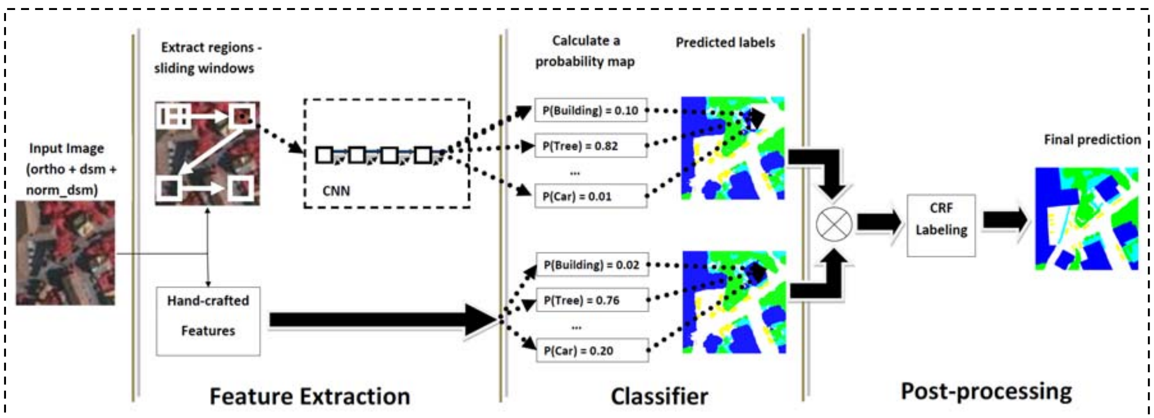
Traditional Algorithms vs. CrackNet



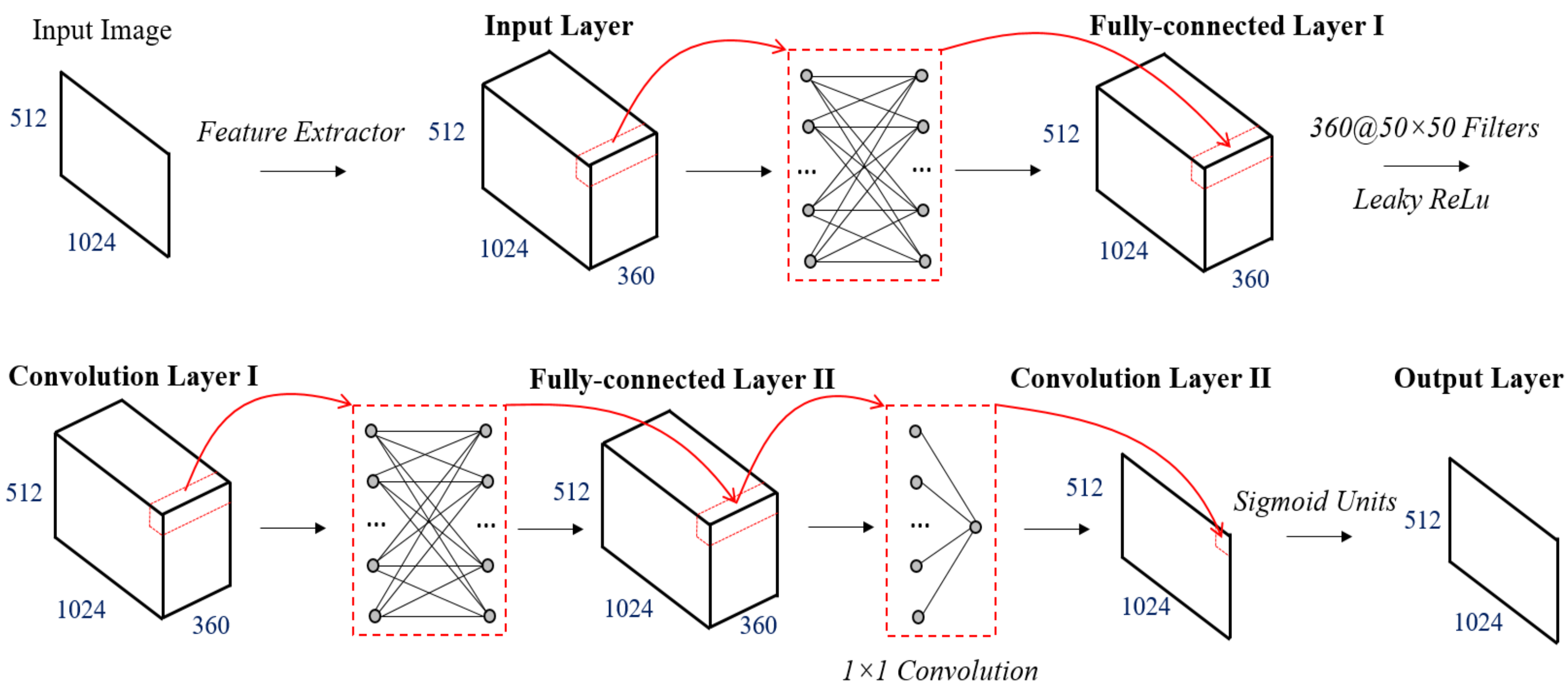
Pixel-Level CNN





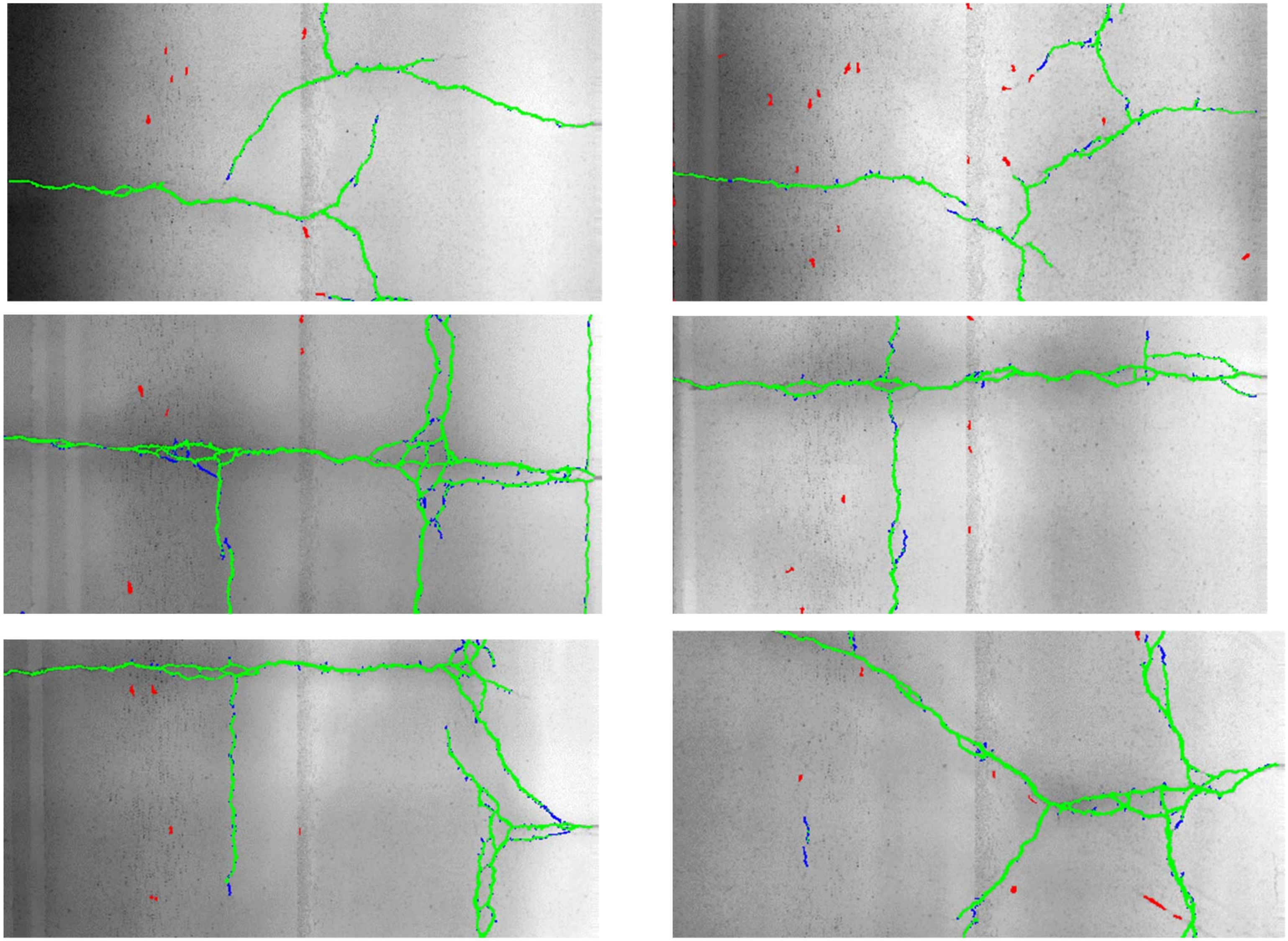


CrackNet for Pixel-Level Accuracy

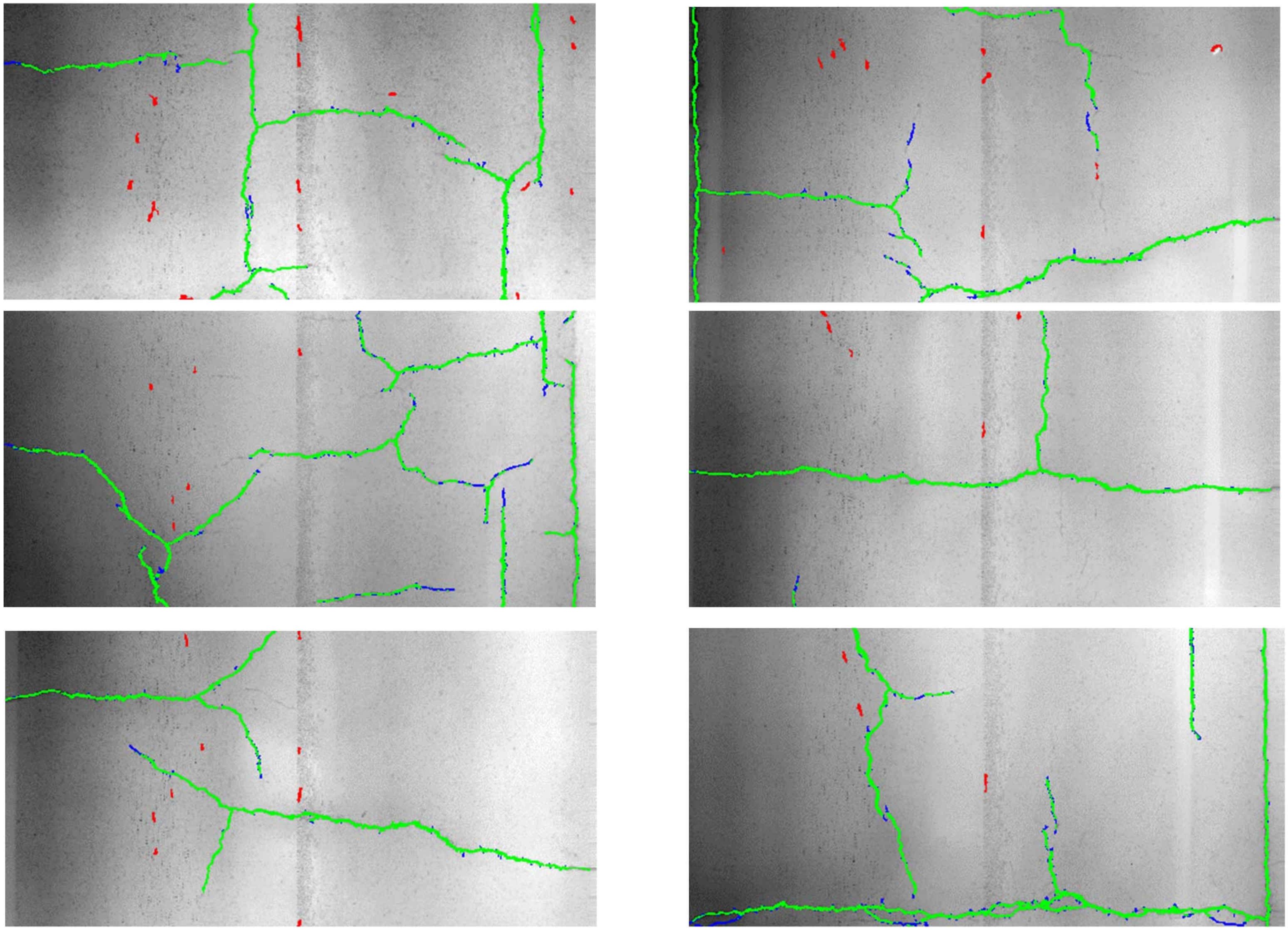


- 7 Layers
- 1,159,561 Parameters

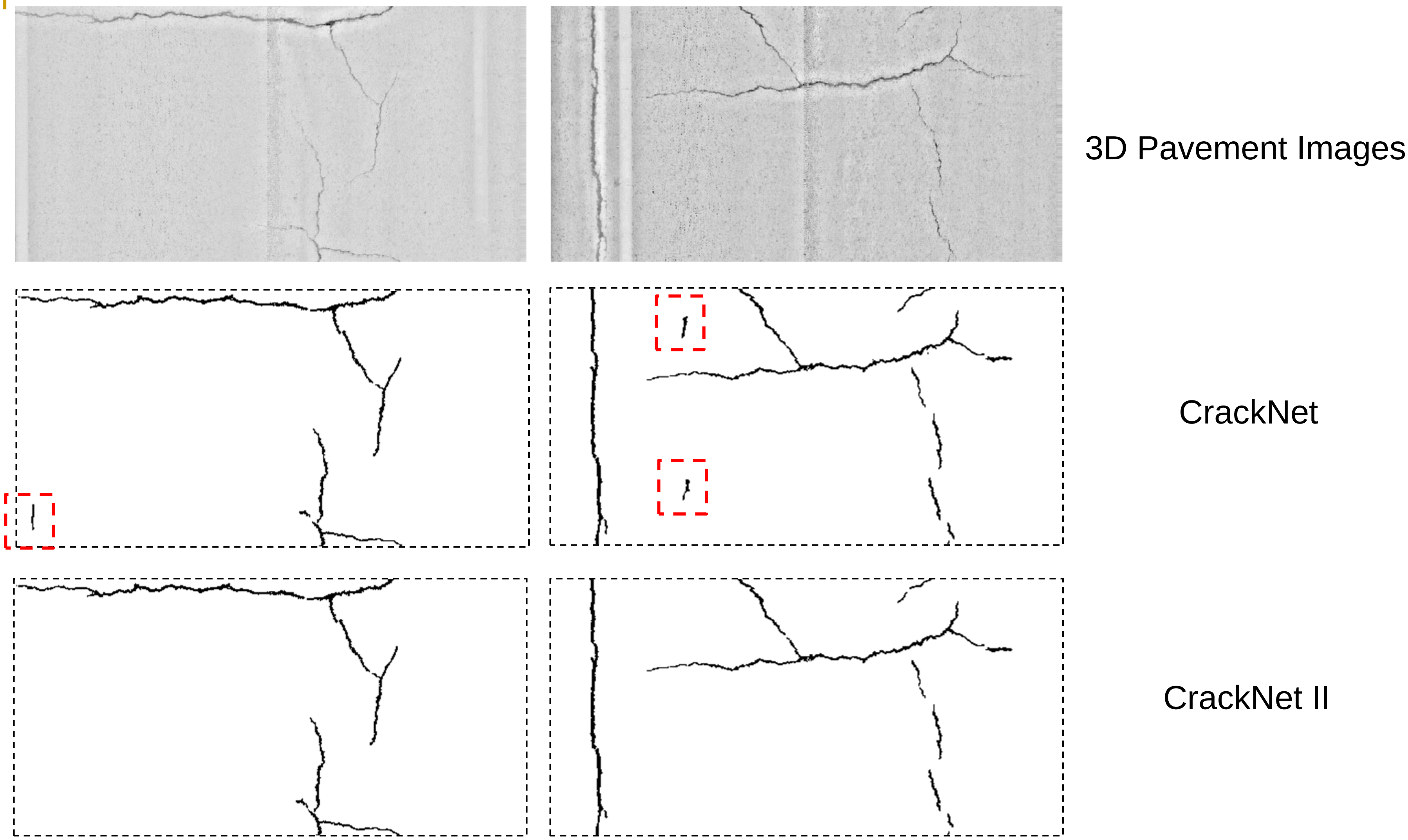
Performance



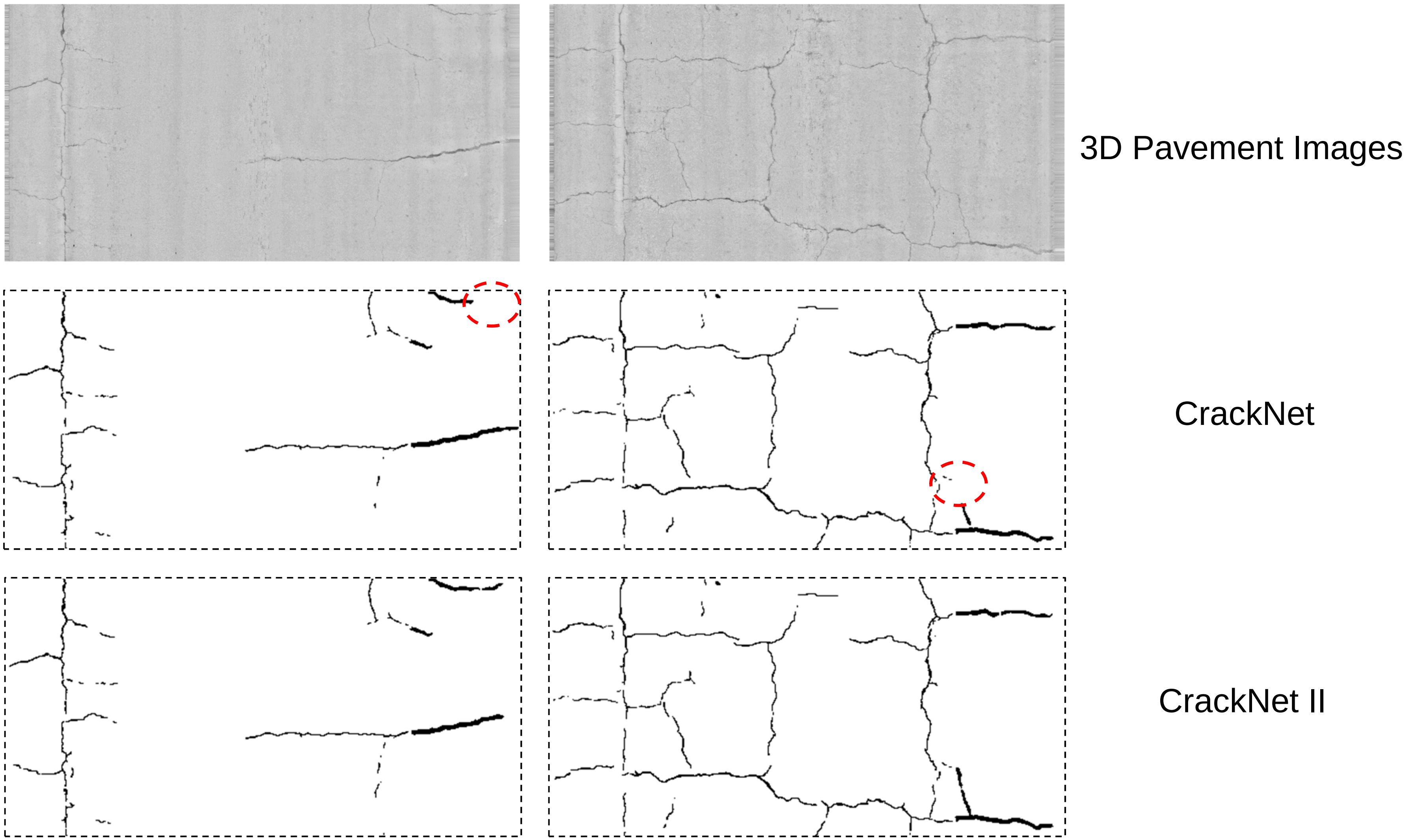
Performance



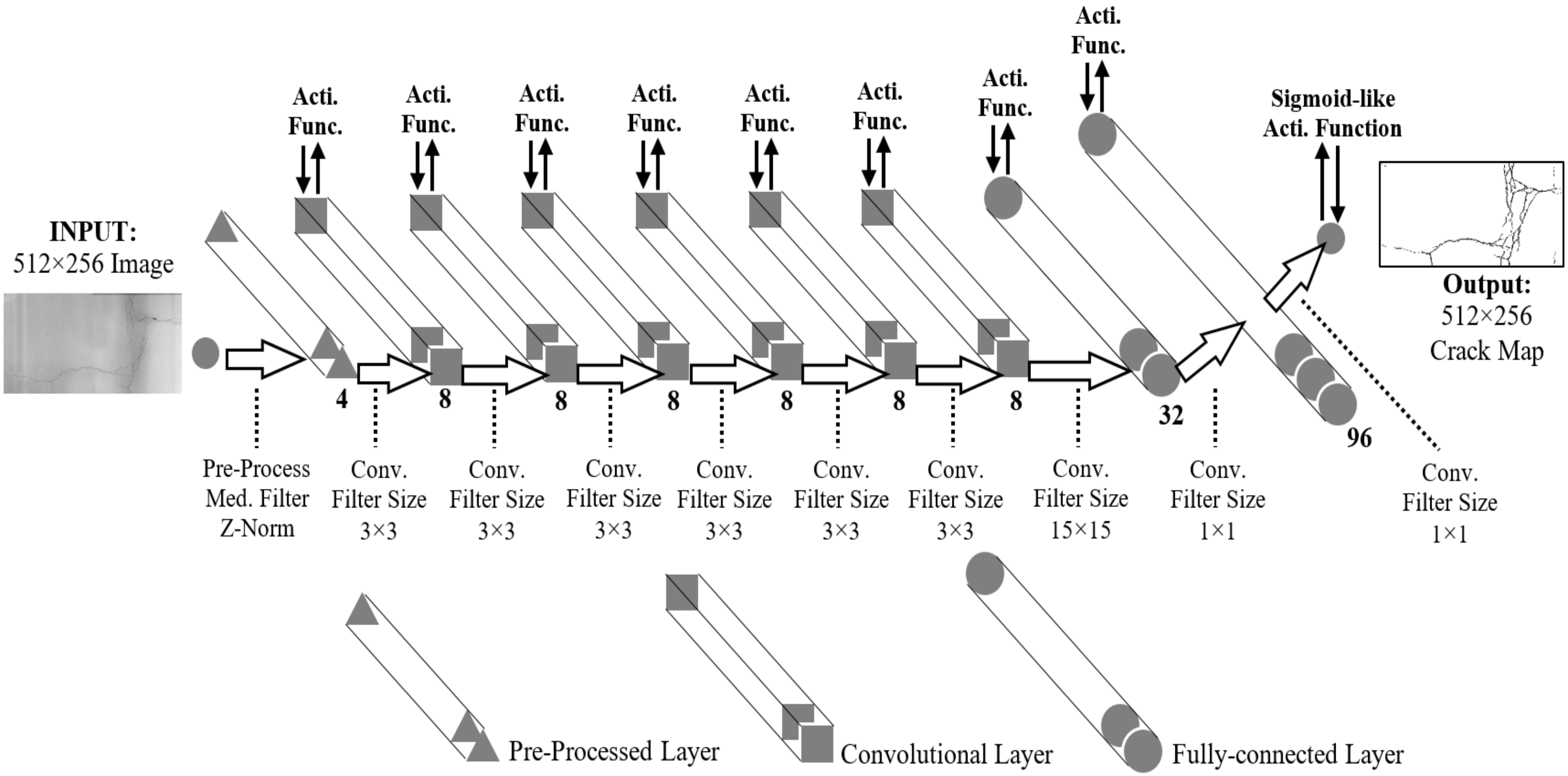
CrackNet vs. CrackNet II in Eliminating Noises



CrackNet vs. CrackNet II in Finding Fine Cracks

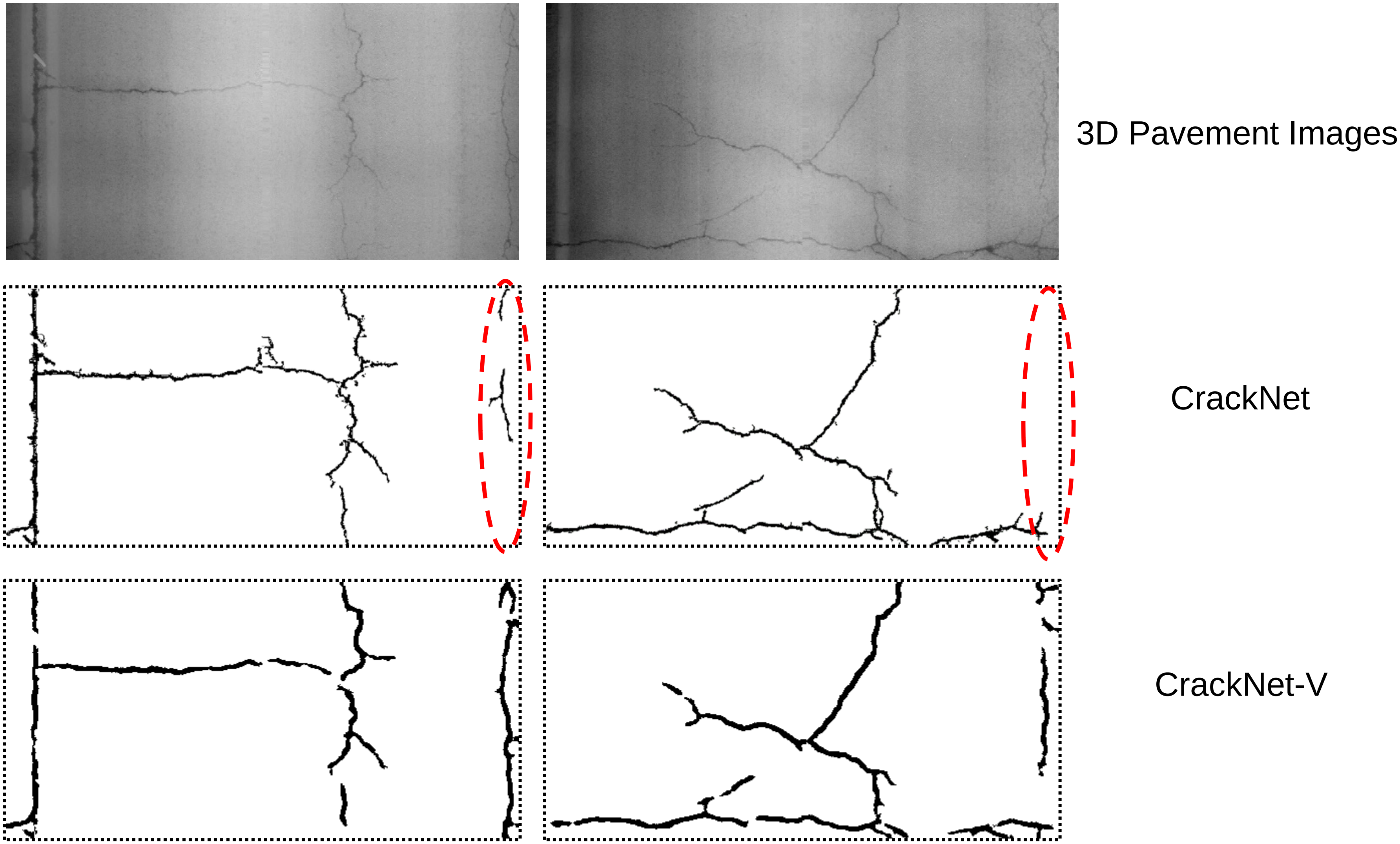


CrackNet-V

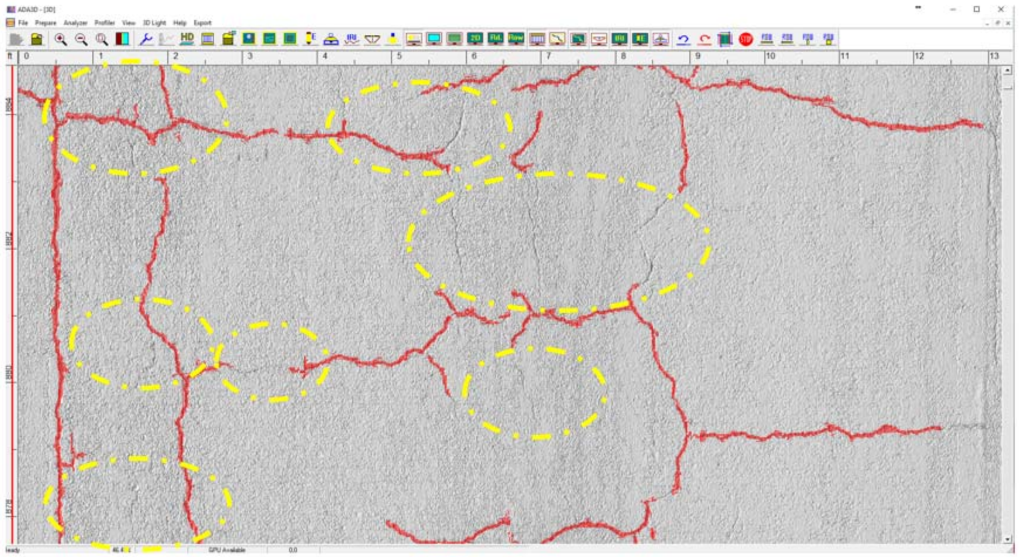


- 9 Layers
- 64,113 Parameters

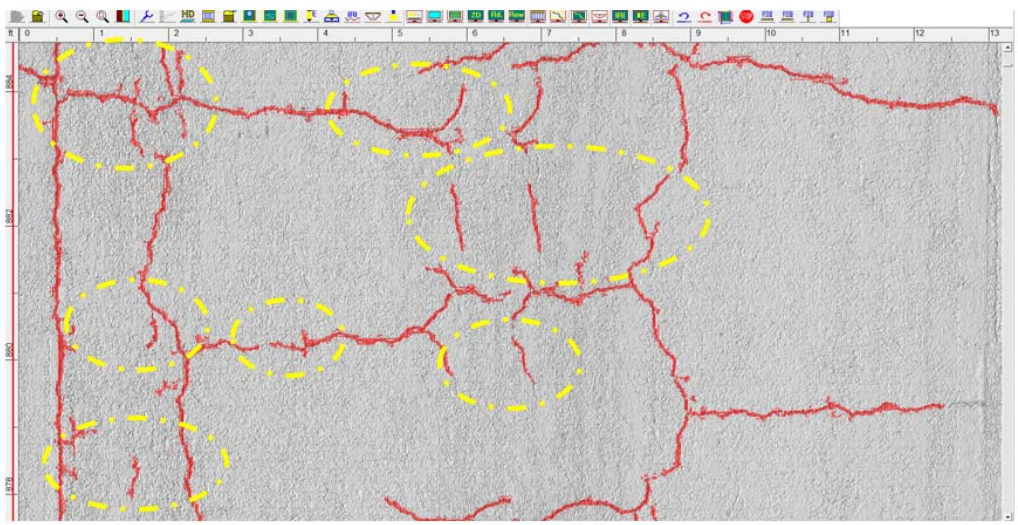
Performance of CrackNet-V



Recurrent Neural Network for Crack Detection

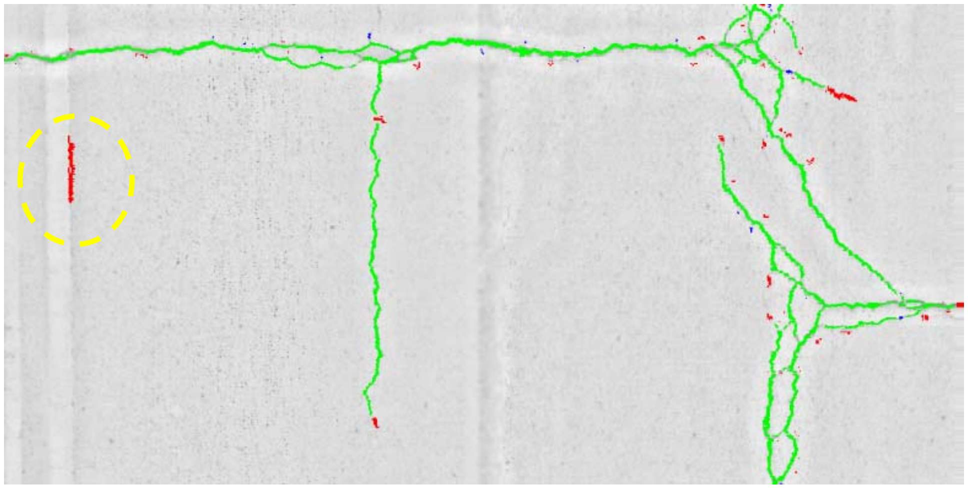


Best CrackNet

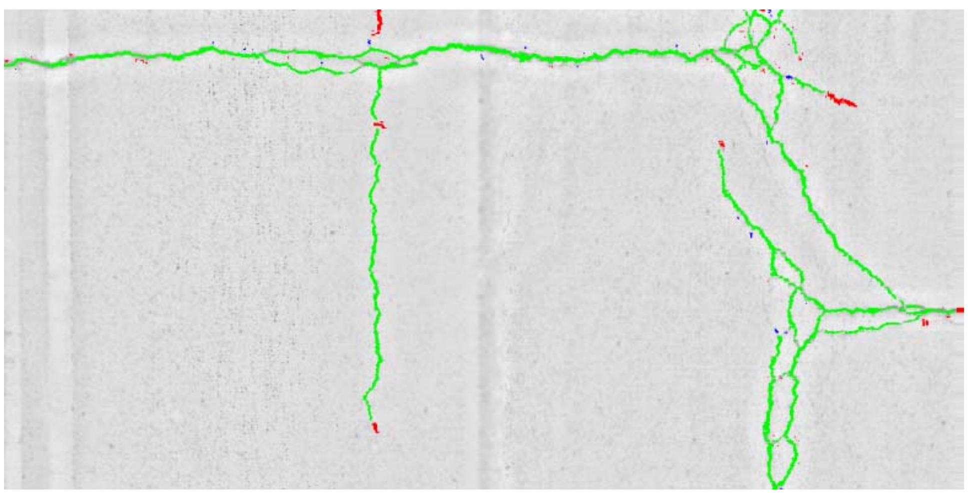


Best CrackNet + RNN

Recurrent Neural Network for Crack Detection

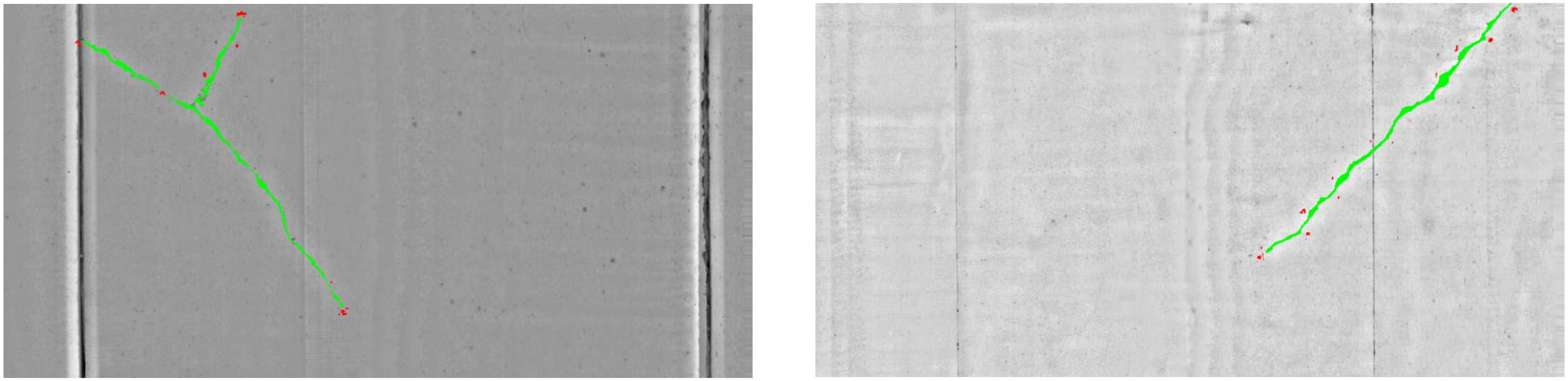


Best CrackNet

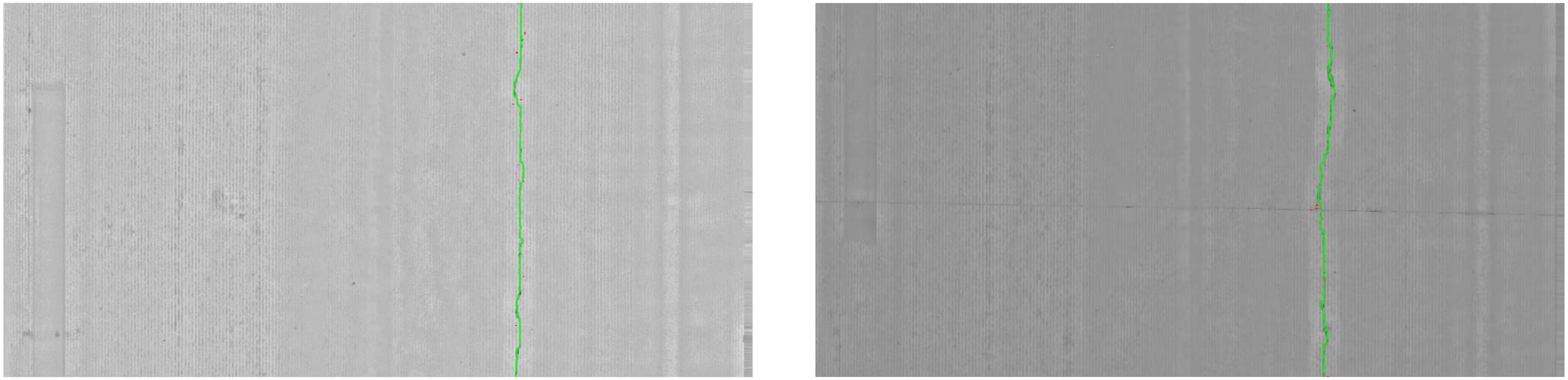


Best CrackNet + RNN

CrackNet on Rigid Surfaces



Jointed Surface



Grooved Surface

Critical Advantages of CrackNet (All Versions)

- Consistency of Precision and Accuracy
  - Different Types of Pavements in Various Conditions
- 90% Precision & Recall: All the Time!
  - False Positives, False Negatives < 10%
- Training of DL Networks: Cumulative
  - Similar to True Learning Process by Humans
- No Need of Tuning Parameters for Different Pavement Surfaces
  - Once Working, Always Working for Any Pavements without Human Intervention

Future Work

- Image Library for Training, Never Ending
  - More Labeled 3D & 2D Pavement Images in Library
  - Variations of Pavement Distresses
  - Artificial Training Data through Augmentation
- Long-term Training & Optimization
  - Field Tests (Diversified Data) for AI Net Optimization
- Self-Taught Learning
  - Unsupervised Learning from Unlabeled Data
- Real-time Application
  - Massively Parallel Computing in a Single Workstation
  - >200MPH Post-Processing?

Conclusions

- Limitations of Traditional Automated Algorithms
  - Inconsistency & Substantial Manual Intervention
- Deep Learning (DL) Based Networks/Solutions
  - Strong capabilities of learning from experiences: cumulative
  - Consistent precision and bias level on various roads
- DL-based Automation with Pixel-Level Accuracy
  - Ready for Production; Continuing for Knowledge Accumulation
- Future: AI/DL is the clear choice!
  - Implementations and Refinements
  - Non-Cracking Distresses
  - Large team: challenge on resources
  - Rail, Tunnel et al

CrackNet:

The New Generation