MONTANA STATE UNIVERSITY
Western Transportation Institute

3D Sensors and AI Solutions for Pavement Distress & Safety Evaluation

Kelvin C.P. Wang, PhD, PE, Dist.M.ASCE
Professor of Civil Engineering
Director of the Western Transportation Institute (WTI)

Montana State University

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Arizona Pavements/Materials Conference
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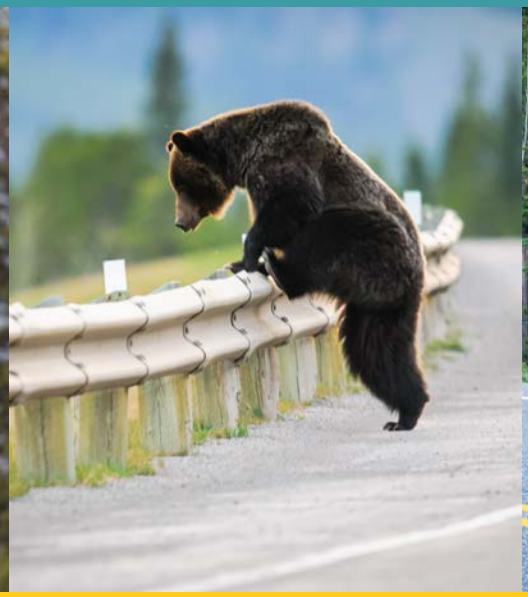
Western Transportation Institute (WTI)

- Major Research Institute in Transportation in the US
- Best Known for Rural Transportation Research
- WTI in Bozeman, MT; Montana State University
  - $11million Annual Research Expenditure at its Peak with 50 Staff Members
  - Substantial Programs in Road Ecology, Safety, Workforce Development, et al
  - Will Grow in Safety Research & Automated Evaluation

US-191/MT-64 Wildlife & Transportation Assessment



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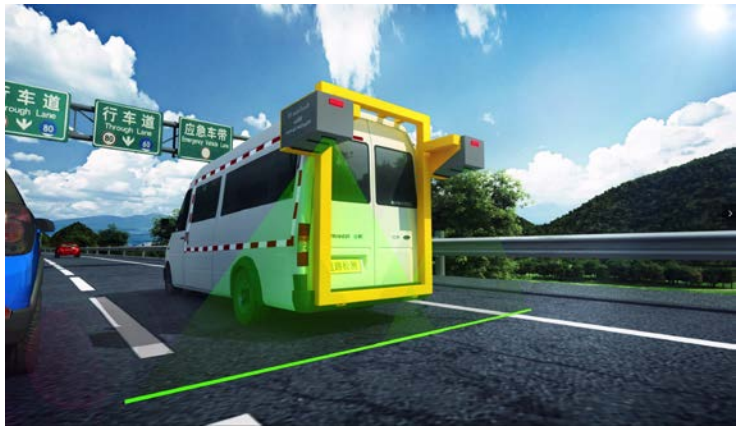
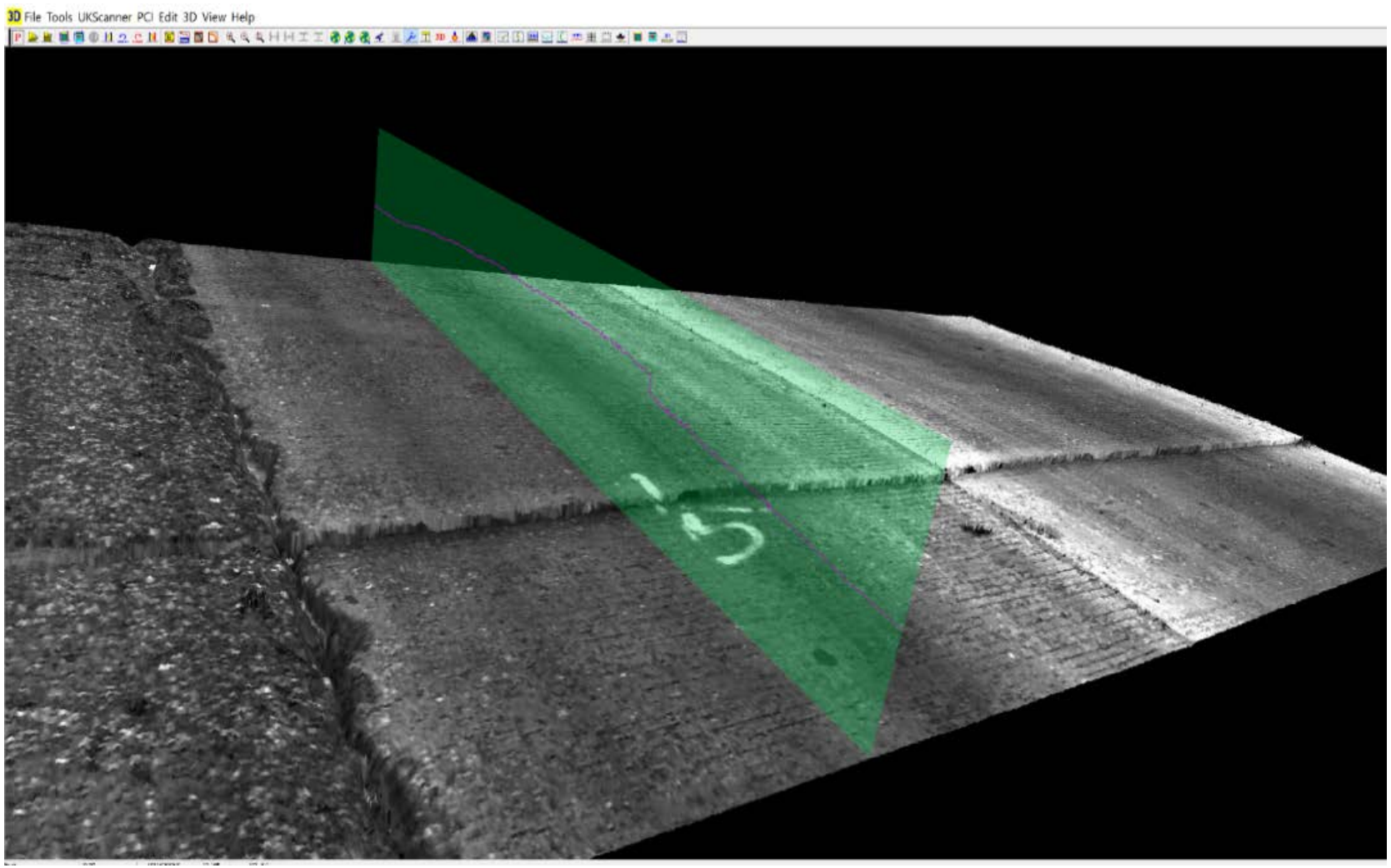
0.5-mm 3D, Pave3D 8K After 30 Years

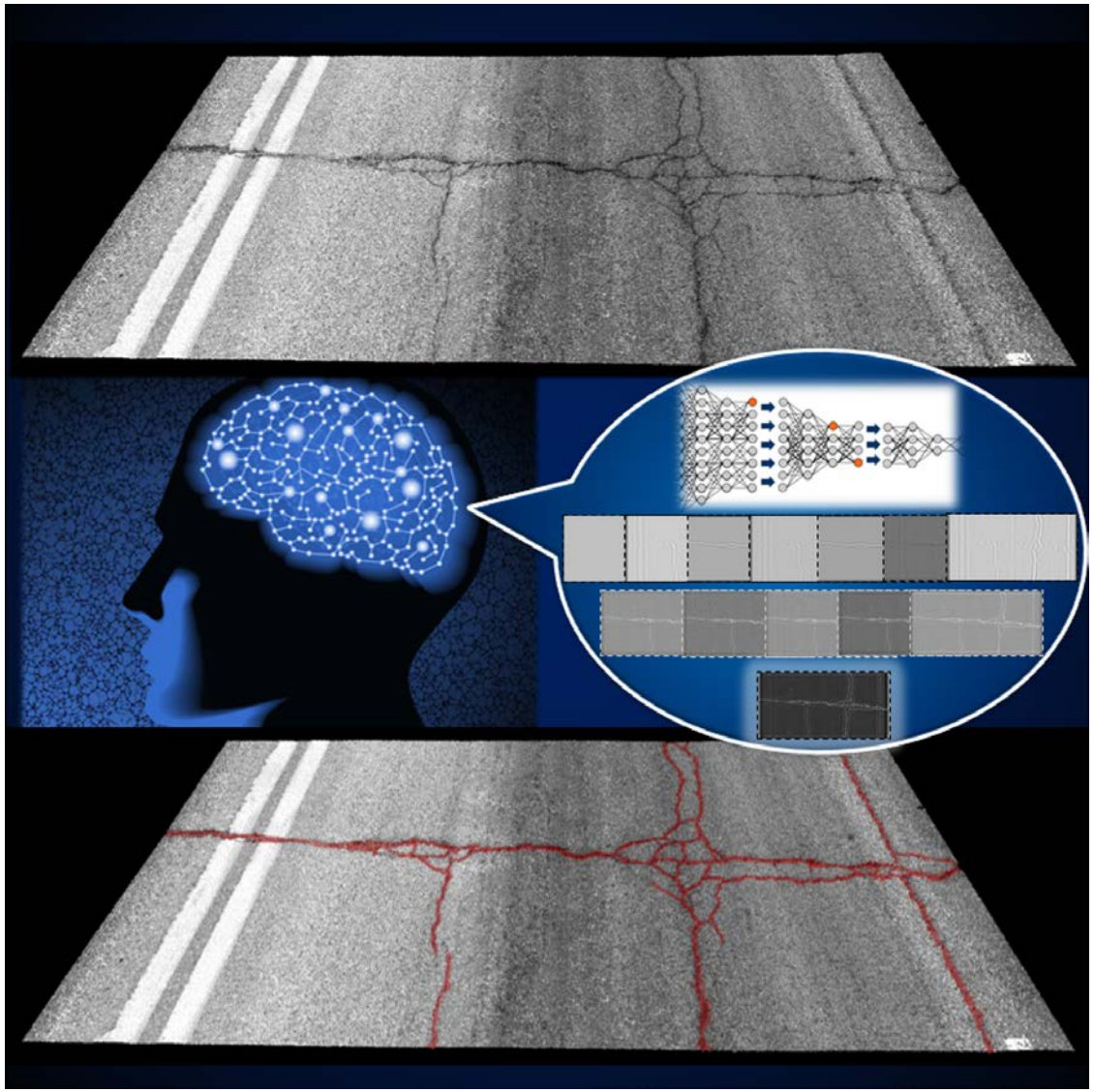
30-Year Commitment

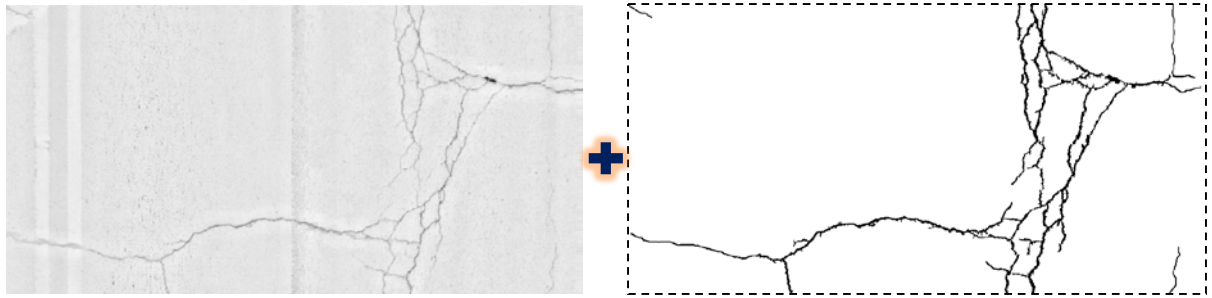




Resolution: 1mm

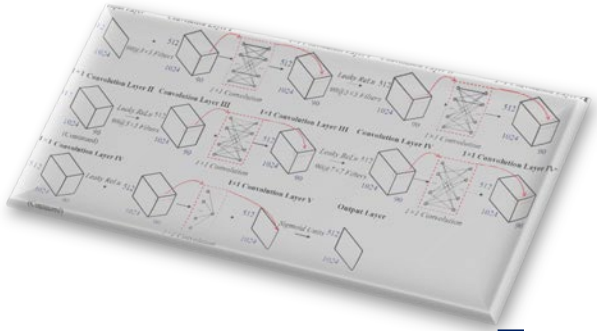
CrackNet



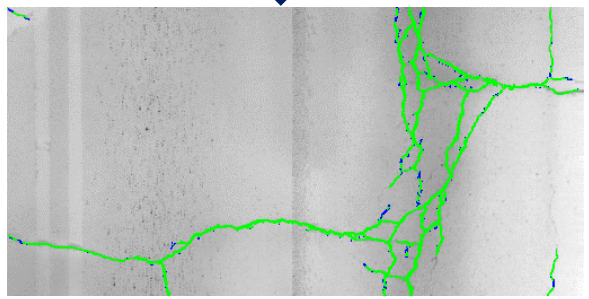


Input Image

Ground-truth



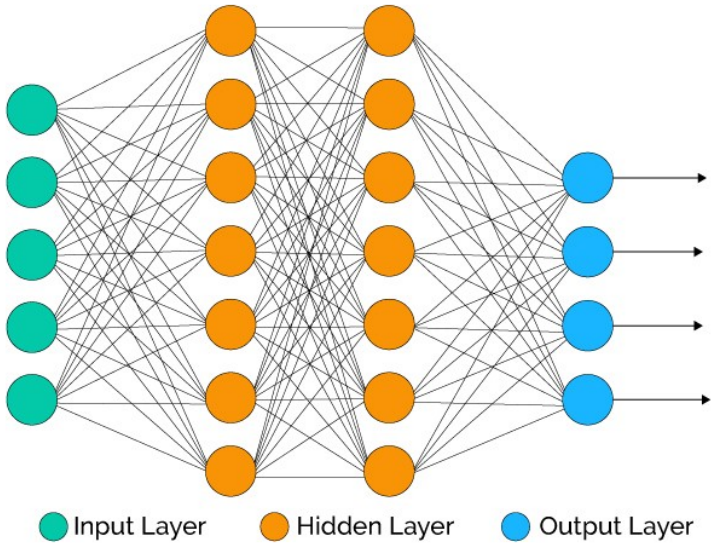
Recursive Training



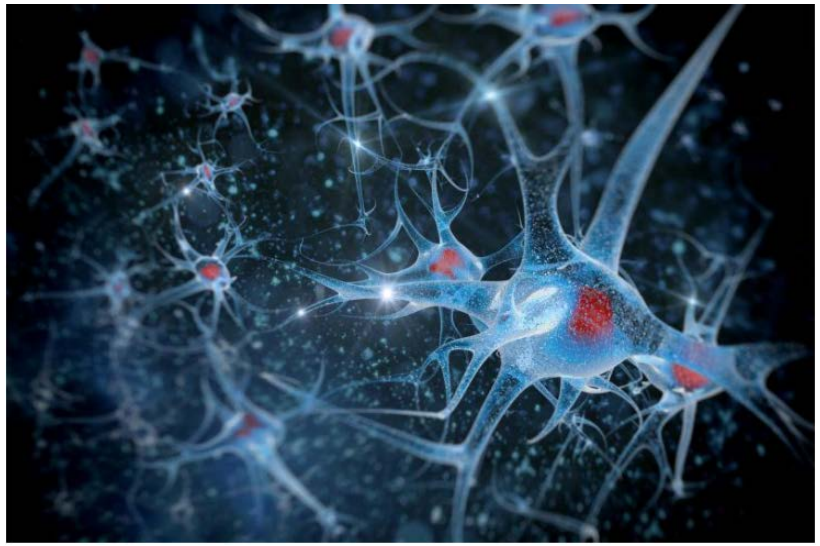
Detection Output with Pixel-Level Accuracy

(Zhang at al. **2017**, in Computer-Aided Civil and Infrastructure Engineering)

Traditional Artificial Neuron Network (ANN)



# of Neurons<10^4

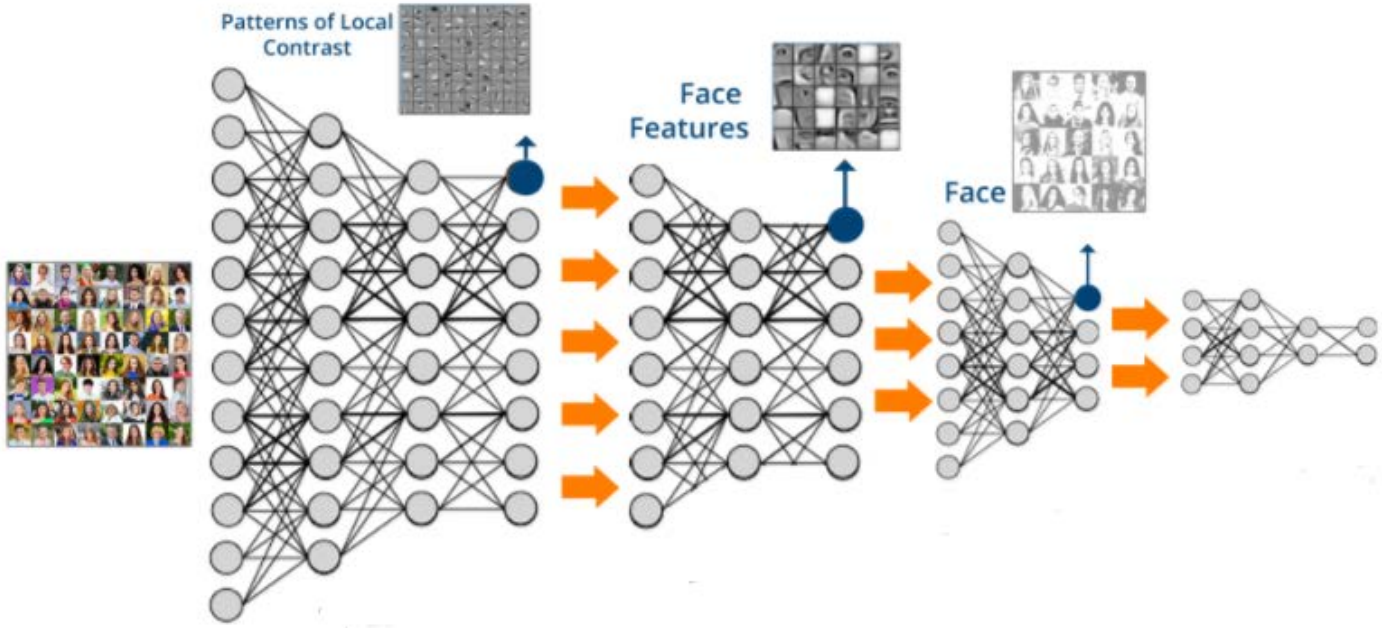


# of Neurons=10^{11} (Human Brain)

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

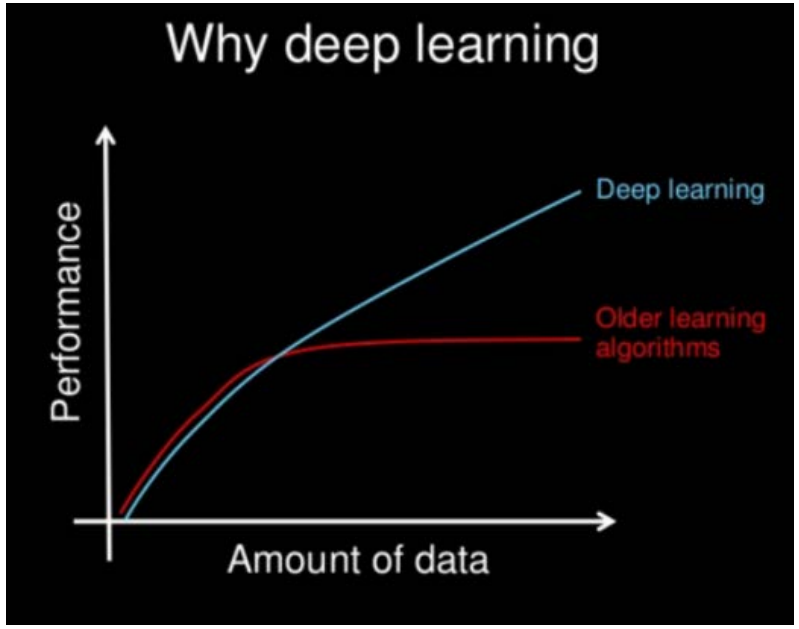
Deep Learning: New Generation of ANN

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



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



Some Insights in Deep Learning

- Artificial Neurons: Simulating Humane Neurons
- Large # of Neurons & Layers
- Key: Connecting Weights between Layers of Neurons
  - Low Dynamic Range of Weights: around 8-bit or less simulating range of signal variations of humane neurons
  - GPUs: perfect for massive parallel processing at low dynamic
  - Very Sparce & Huge Matrix Operations: new hardware (GPU et al)
- Many New Methods on Deep-Learning by Large Firms
  - Innovations to determine weights for higher performance
- Learning/Training and Inferencing: two separate processes

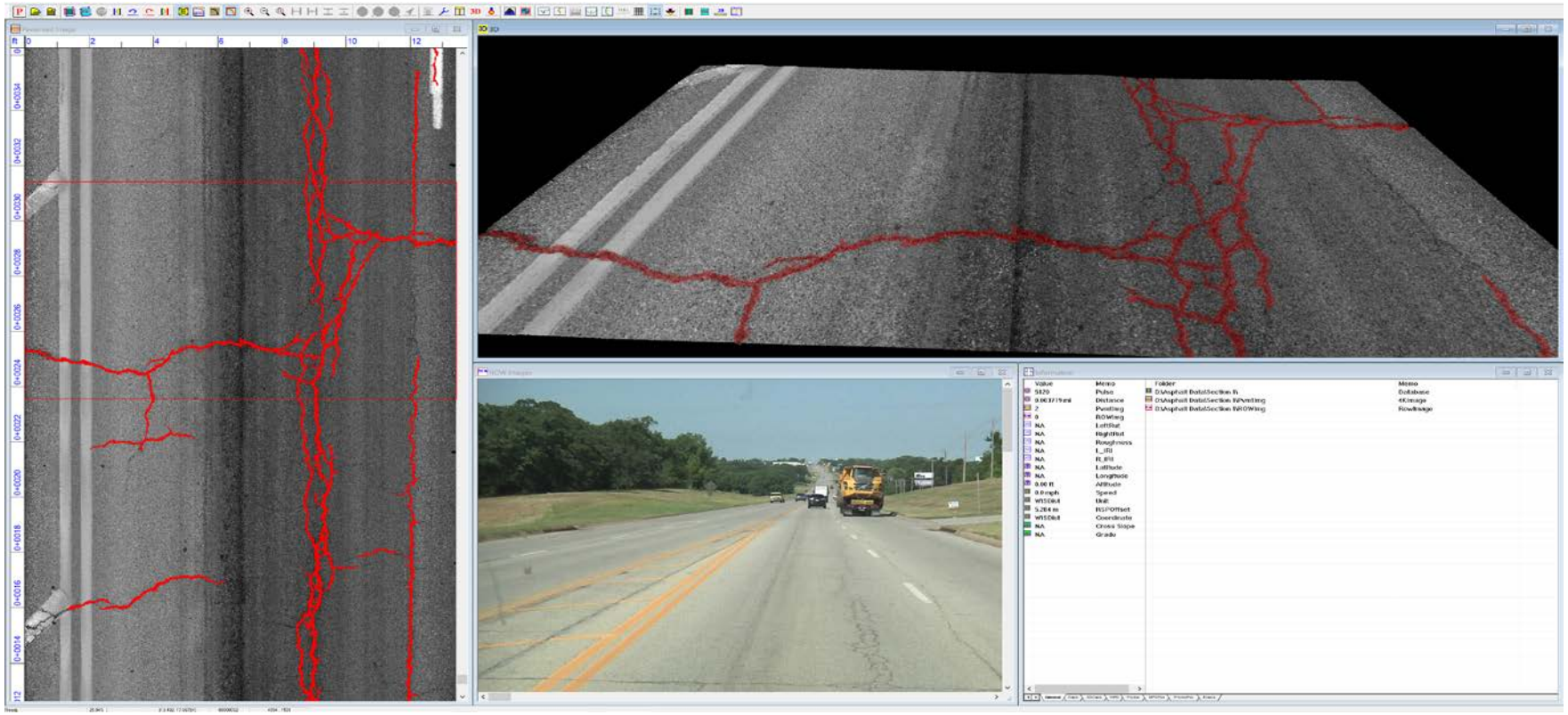
Applications of Deep Learning

- Cognition based Classification
  - Perfect for Cracking Identification, like CrackNet
  - Can be very fast depending on GPU & Platform
- Other Problems in Pavement Evaluation
  - Non-Cracking Visual Distresses
  - Pavement Safety
- “Long-Shot” Pavement Problems
  - Relating Surface Deflections to Layers’ Moduli?
  - Pavement Materials Properties
  - Specific Challenges in ME based Pavement Design

Two Applications

- Multi-Objective DL for Distresses
- Safety Sensor at 0.1-mm or Higher Resolution

Recent Developments of CrackNet



- Real-time Collection & Detection
- Processing Speed: 90 MPH

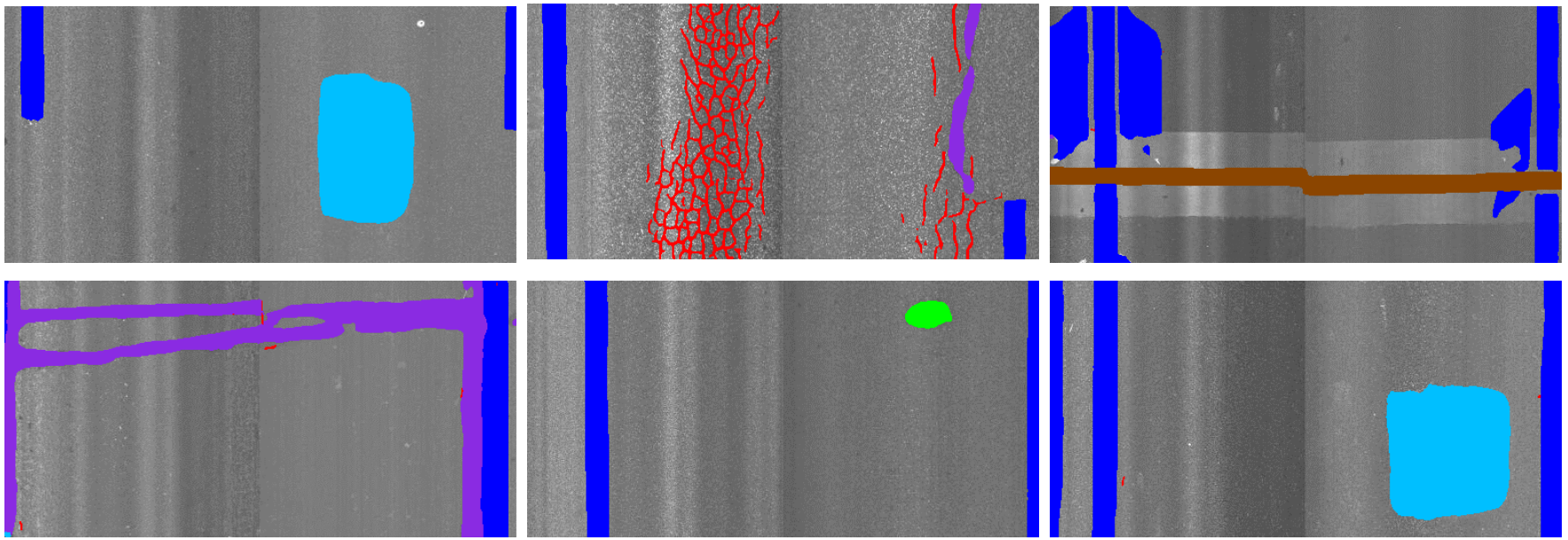
Multiple-Distress

- ❑Pixel-Level Accuracy, Diverse Training Data
- ❑Deep Neural Networks, Parallel Computing, Efficiency
- ❑Non-Cracking Distresses
- ❑Real-Time Processing
- ❑Consistent Accuracy (Precision & Bias)
  - ❑Better than 90% All the Time

Intelligent pixel-level detection of multiple distresses on asphalt pavements

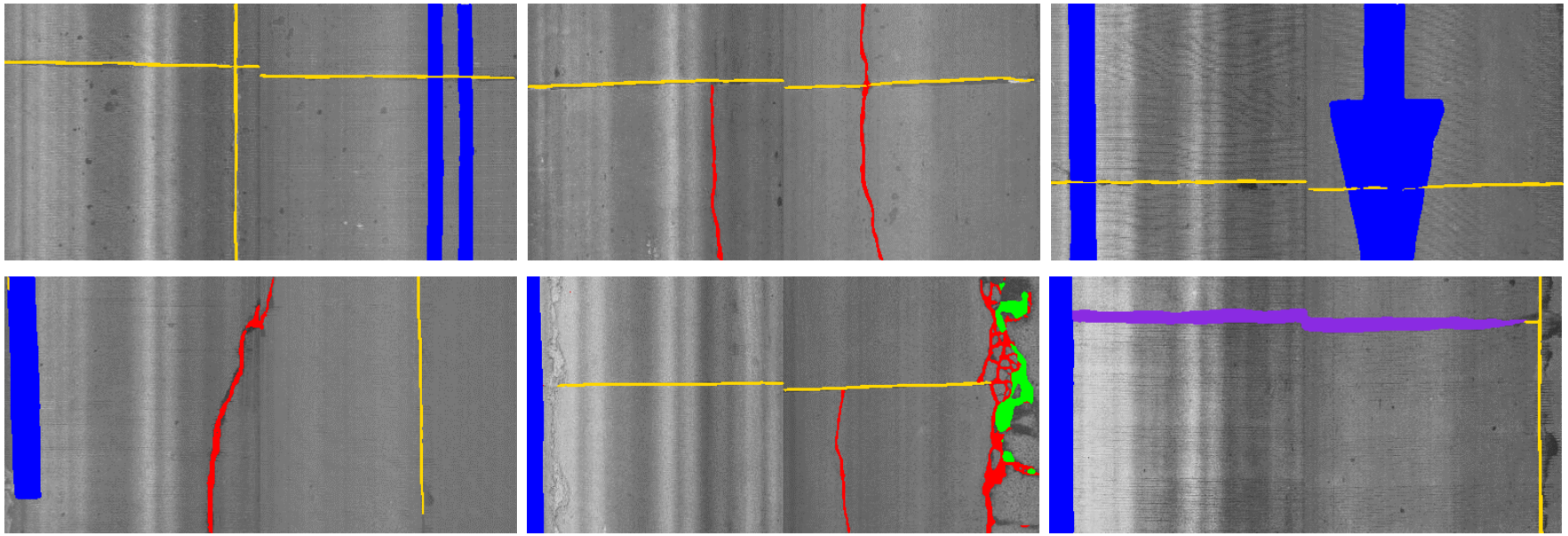
2022/11 Computer-Aided Civil and Infrastructure Engineering

Multi-Distress Single-Network on AC



- Distresses and typical patterns
  - Crack, Pothole, Patch, Sealing, Marking, Expansion Joint, Manhole
- Performance Goals
  - Pixel-level accuracy: >90%
  - Processing Speed: >200 Kilometer Per Hour

Multi-Distress Single-Network on Rigid



- Distresses and typical patterns
  - Crack, Pothole, Corner break, Divided slab, Sealing, Patch, Joint spalling, Joint, Marking, Manhole
- Performance Goals
  - Pixel-level accuracy: >90%
  - Processing Speed: > 200 Kilometer Per Hour

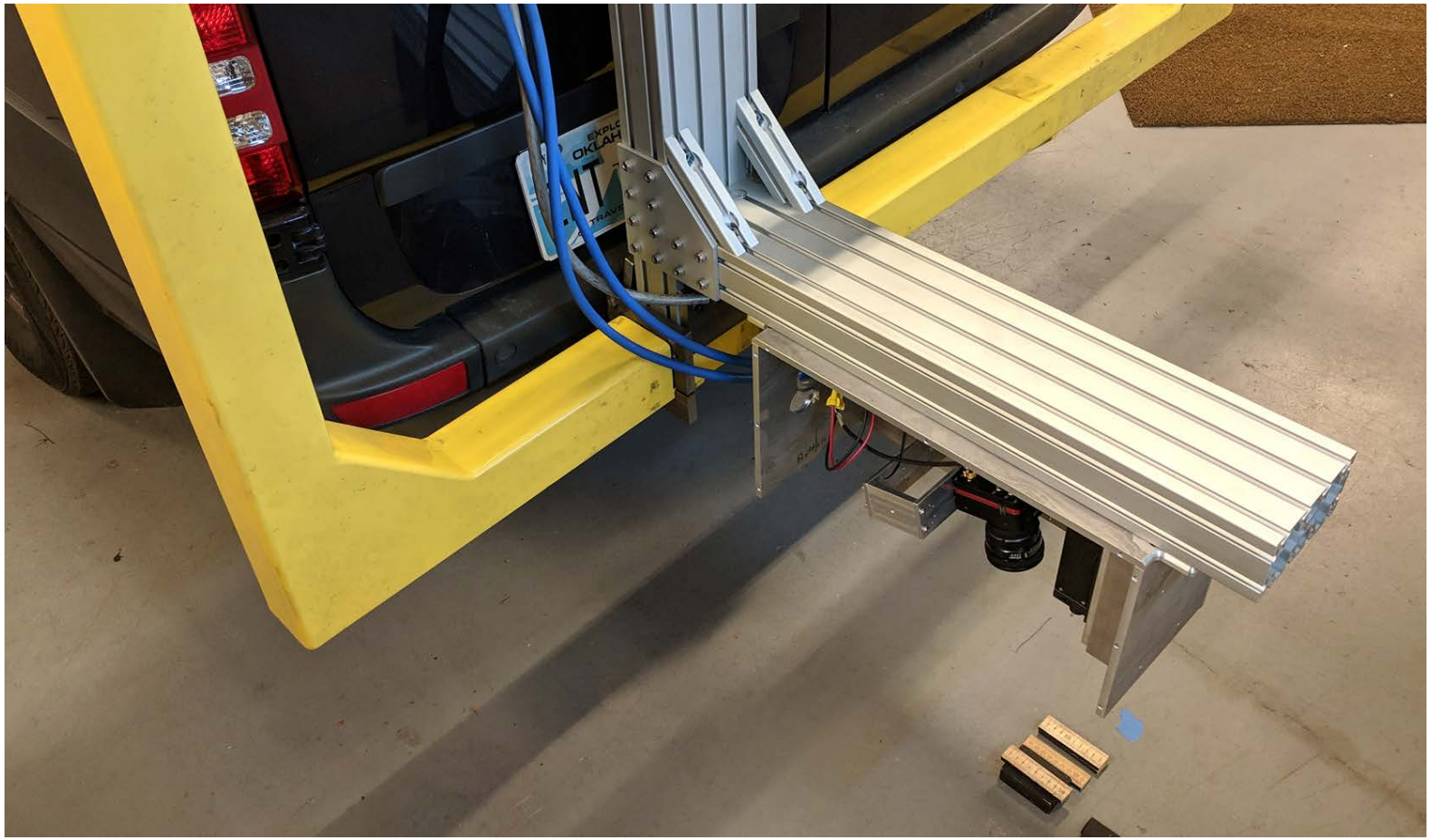
Introduction to Non-Contact Safety Sensor

- Pavement texture, friction, and hydroplaning: three main aspects in performing pavement safety evaluations
- Not possible: micro-texture at highway speeds
- Current friction testing devices: expensive, hard to maintain, unable to perform network friction evaluation, & data accuracy-repeatability in question
- Need a new approach to collecting pavement safety information in a true non-contact and continuous manner for network survey

Factors in Pavement Safety Evaluation

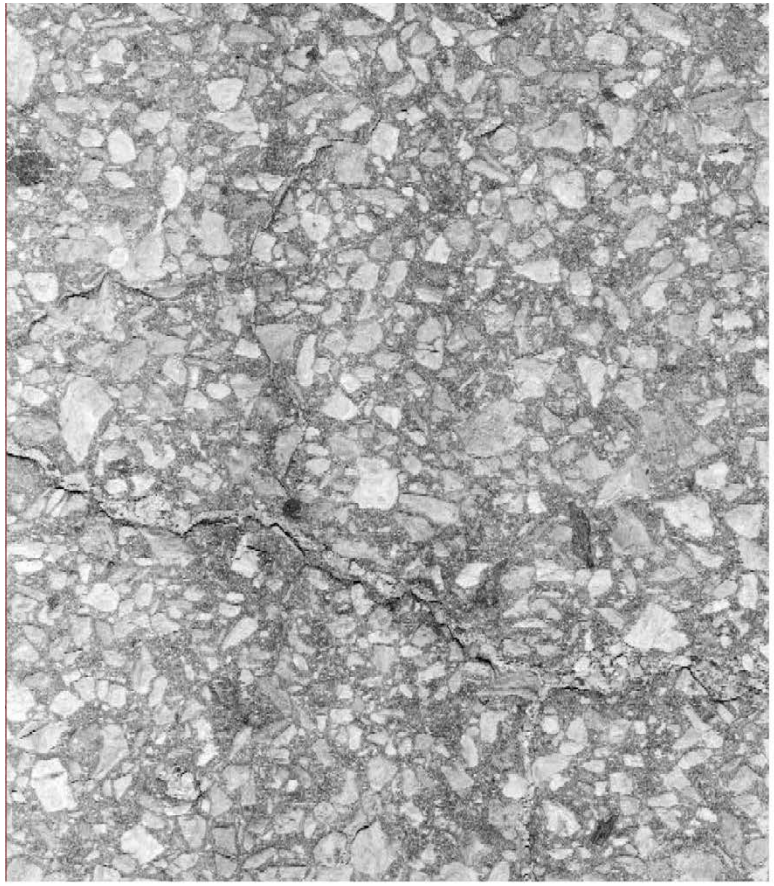
- Pavement texture, friction, and hydroplaning: three main aspects in performing pavement safety evaluations
- The number and severity of traffic crash: increase when roadway sections have low friction numbers or texture depth
- Highway locations with a propensity for hydroplaning: identified and corrected with proper remedies to minimize the potential safety risks

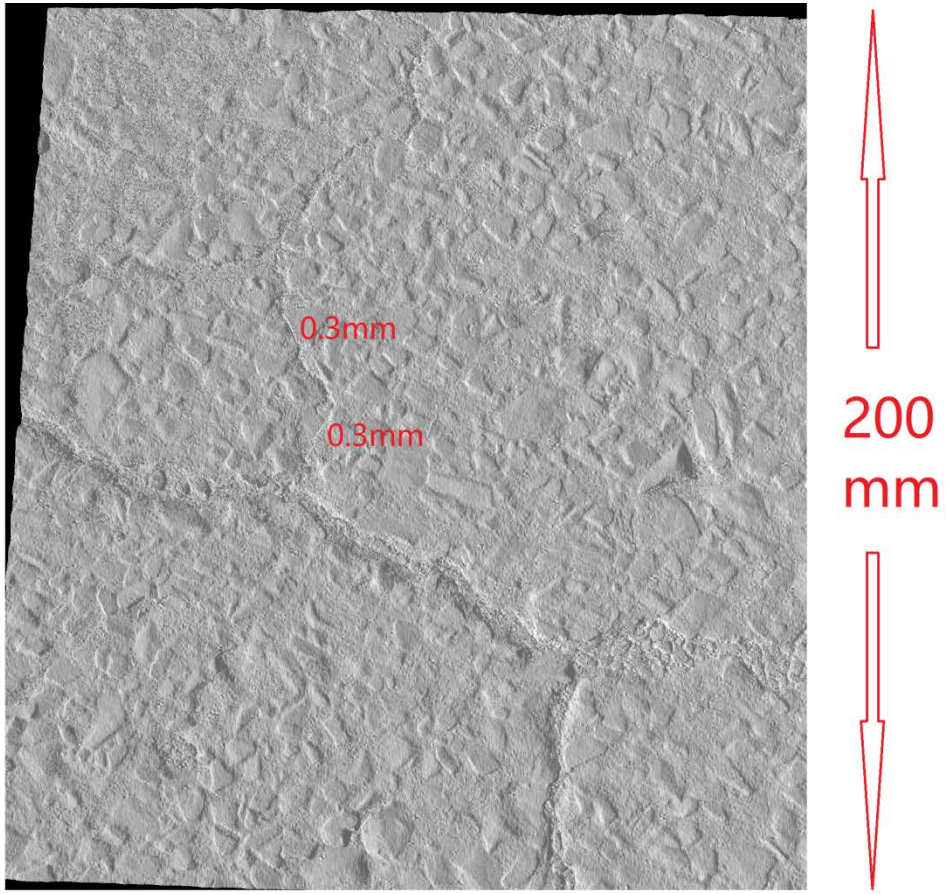
Prototyping 0.1-mm 3D Laser Imaging



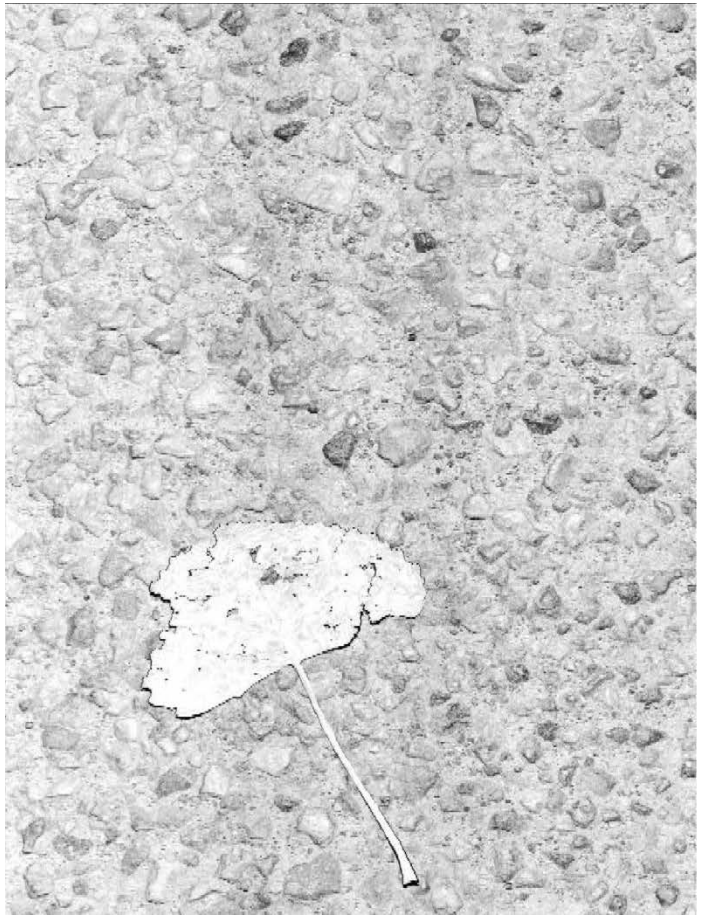
Current 0.1-mm 3D Safety Sensor

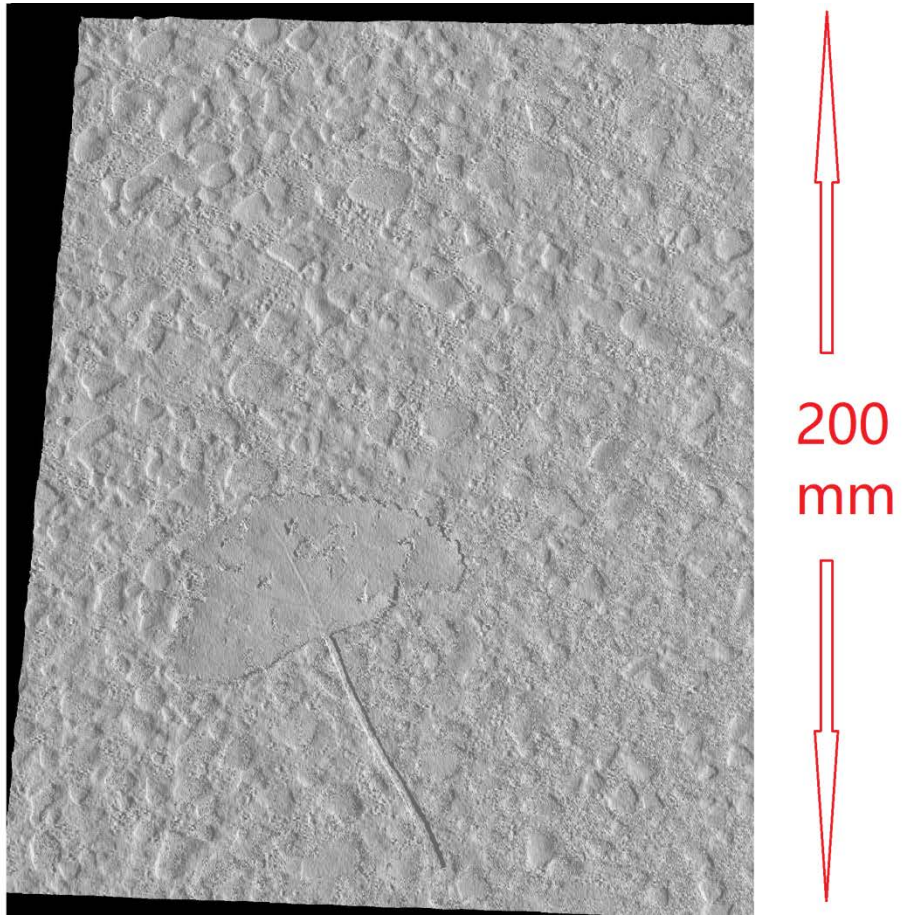
Samples of 0.1mm 3D Pavement Surface



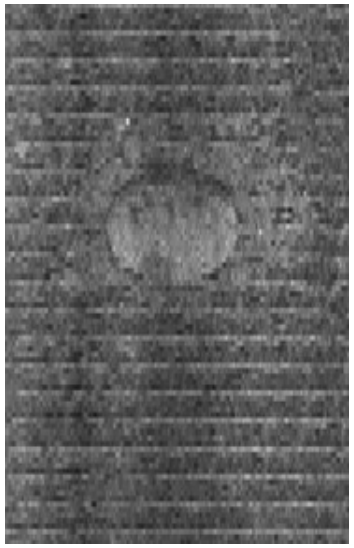


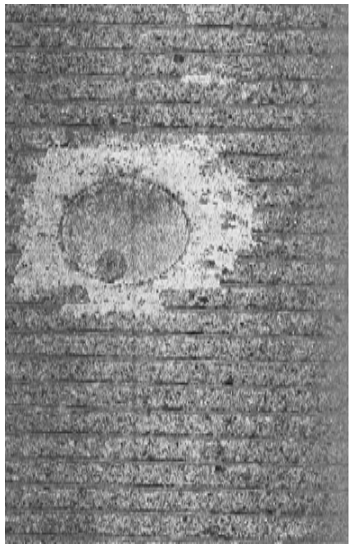
Samples of 0.1mm 3D Pavement Surface



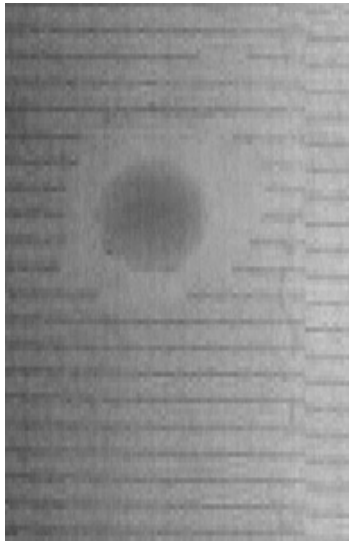


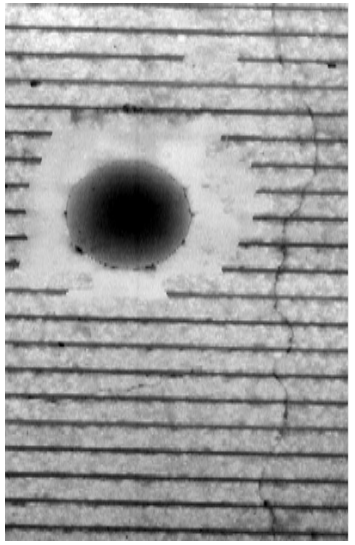
Example Images at An Exact Location





2D



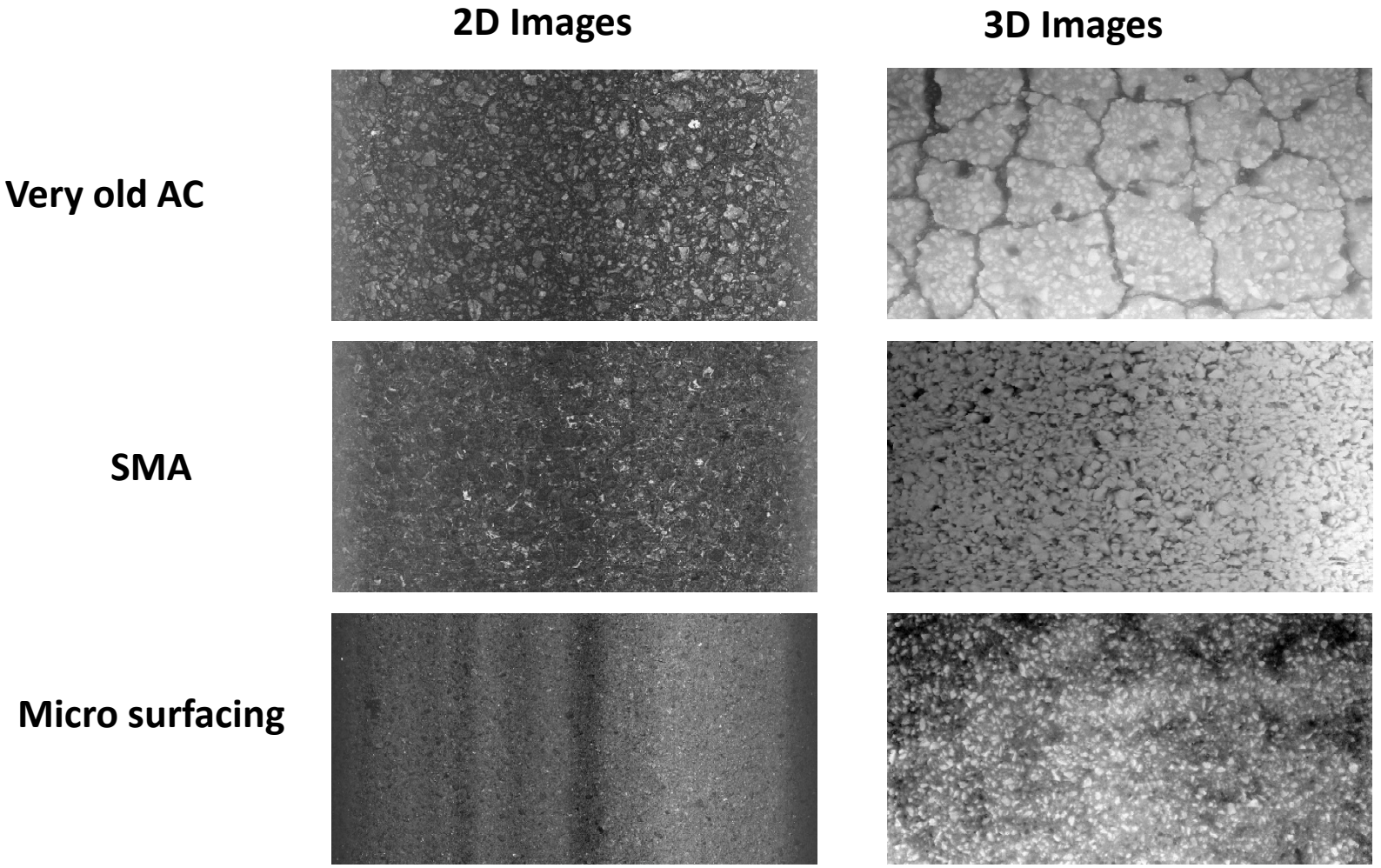


3D

0.5 mm

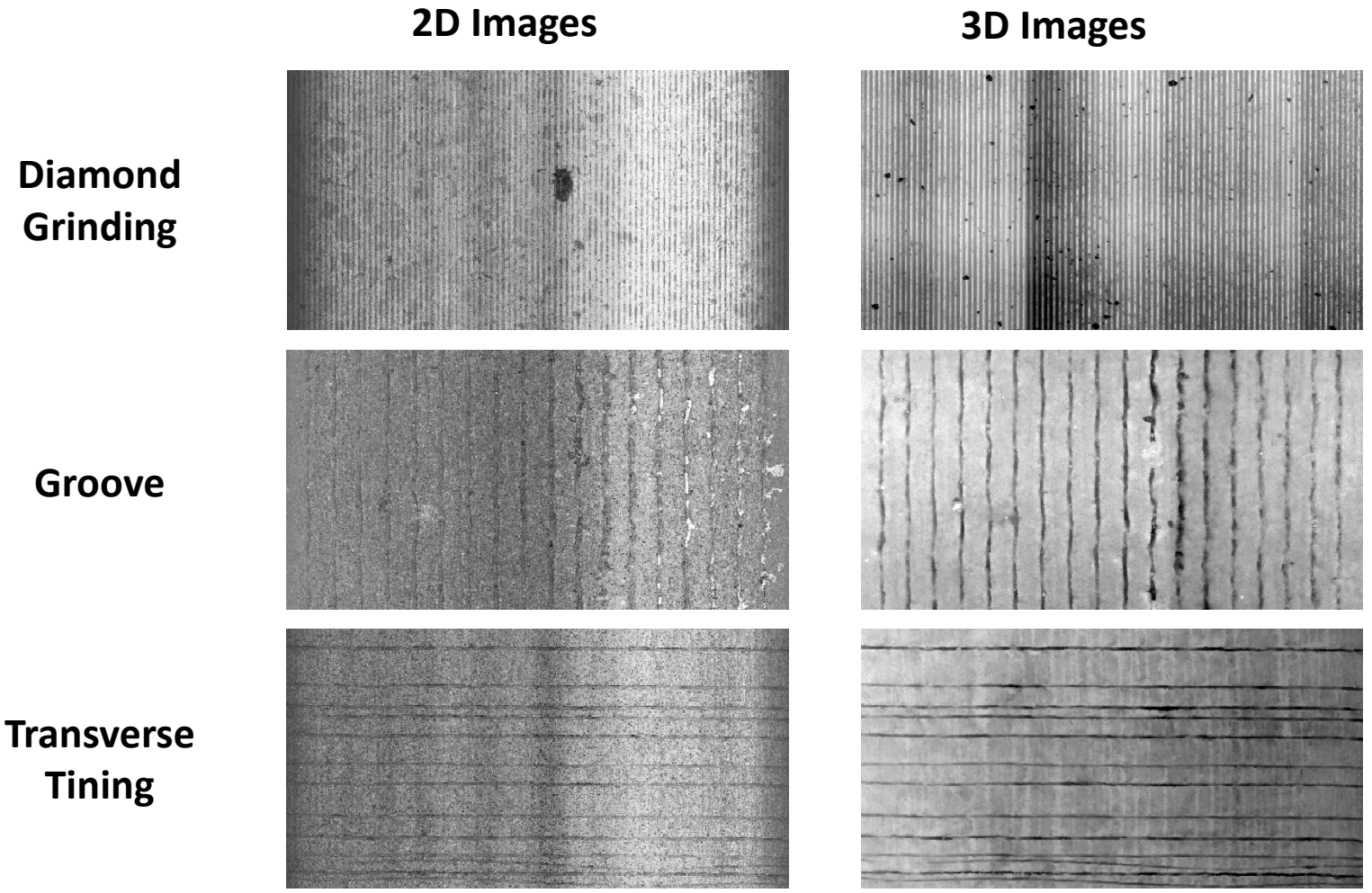
0.1 mm

Example Images of 0.1 mm Safety Sensor



Asphalt Pavements

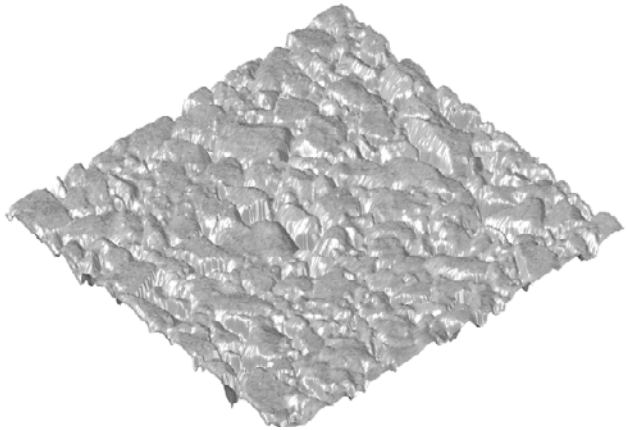
Example Images of 0.1 mm Safety Sensor



Concrete Pavements

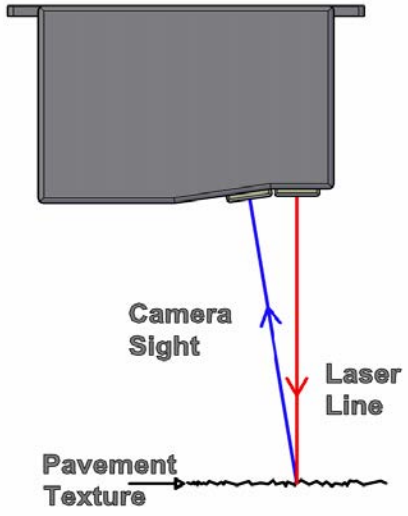
Need of Ultra-High Resolution for Safety Sensor

- Using three-dimensional (3D) imaging technology for pavement texture evaluation
- Stationary devices for 3D texture evaluation
  - Collect high resolution 3D texture images statically
  - Unable to conduct network texture evaluation



Objective

- Reconstruct 0.1 mm 3D texture data using PT-SRGAN at highway speed
  - 0.1 mm 3D data along transverse direction
  - Resolution along longitudinal/travel direction
  - Need to increase the longitudinal/travel resolution
  - Super Resolution (SR) Techniques

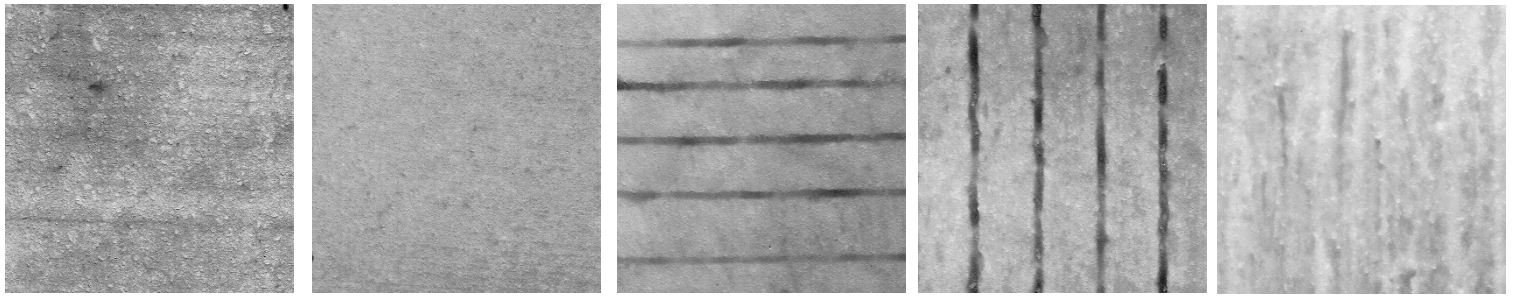


Data Collection

- Collect true 0.1 mm texture data at a speed < 1 mph via 0.1 mm 3D Safety Sensor
  - 10 road surface types (5 AC and 5 PCC)
  - 1468 images for model training, validation, and testing

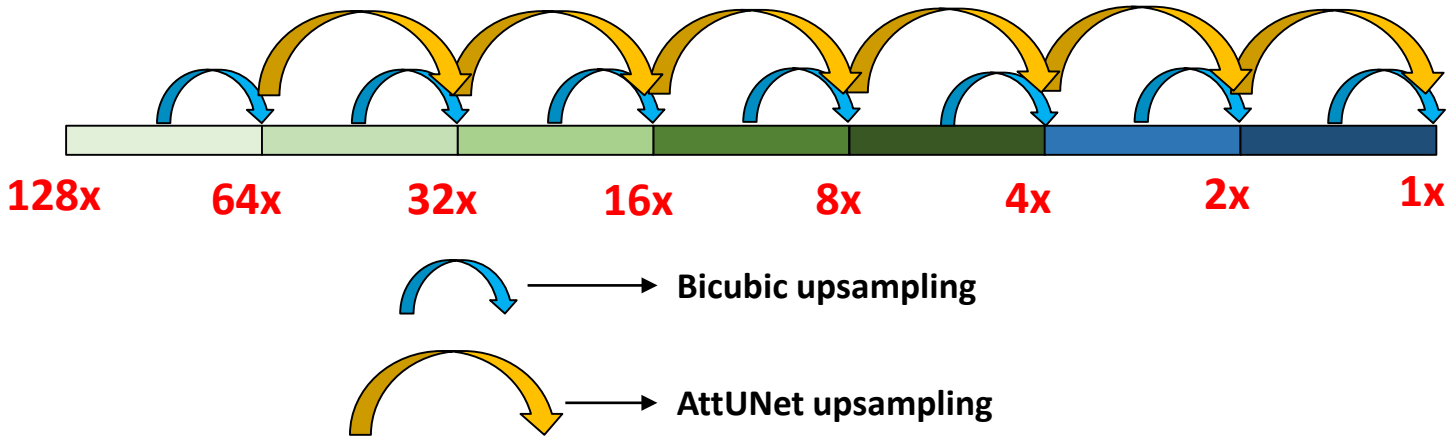
5 AC

5 PCC



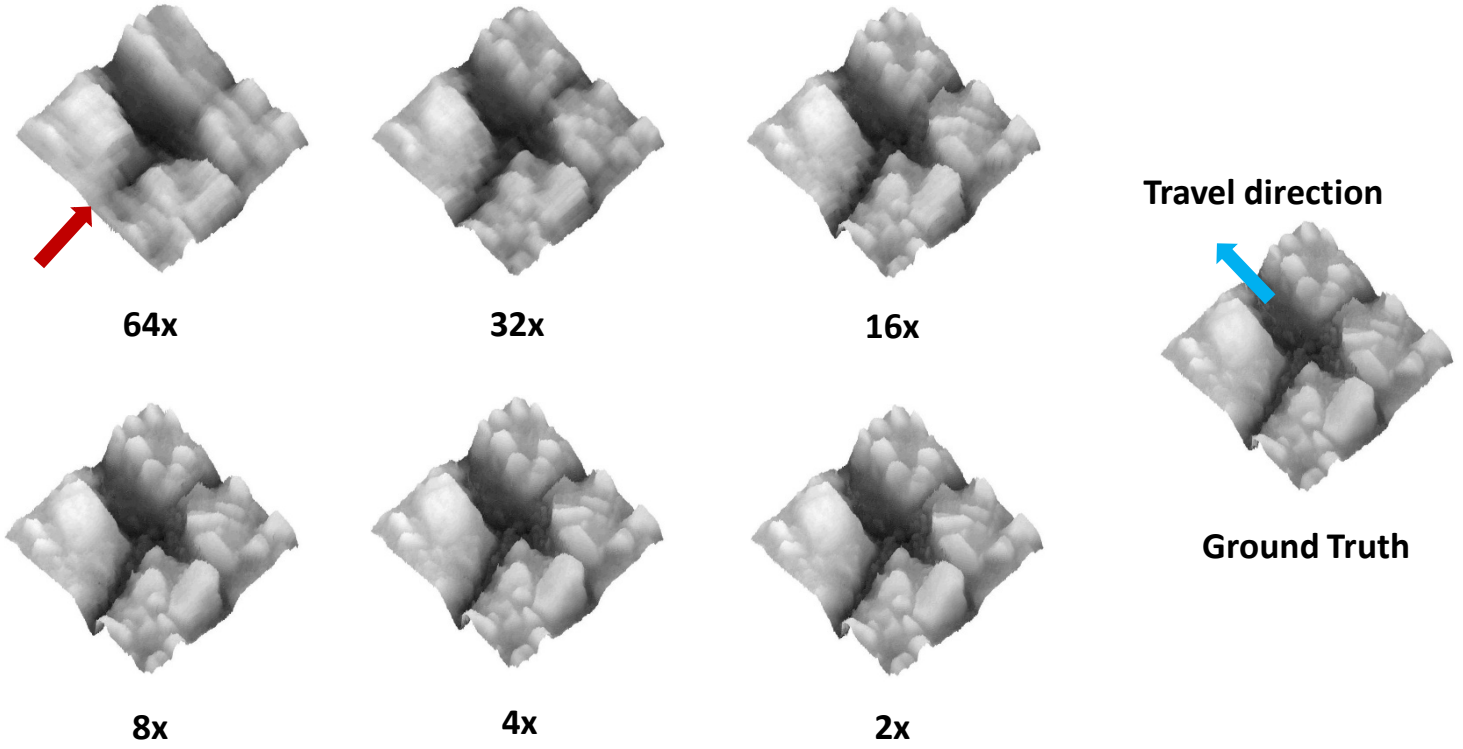
Recursive GAN on Akin-Laplacian Pyramid

- Advantages
  - High upscaling factors: up to 64x
  - Any upscaling factor in combination with bicubic upscaling at each scale



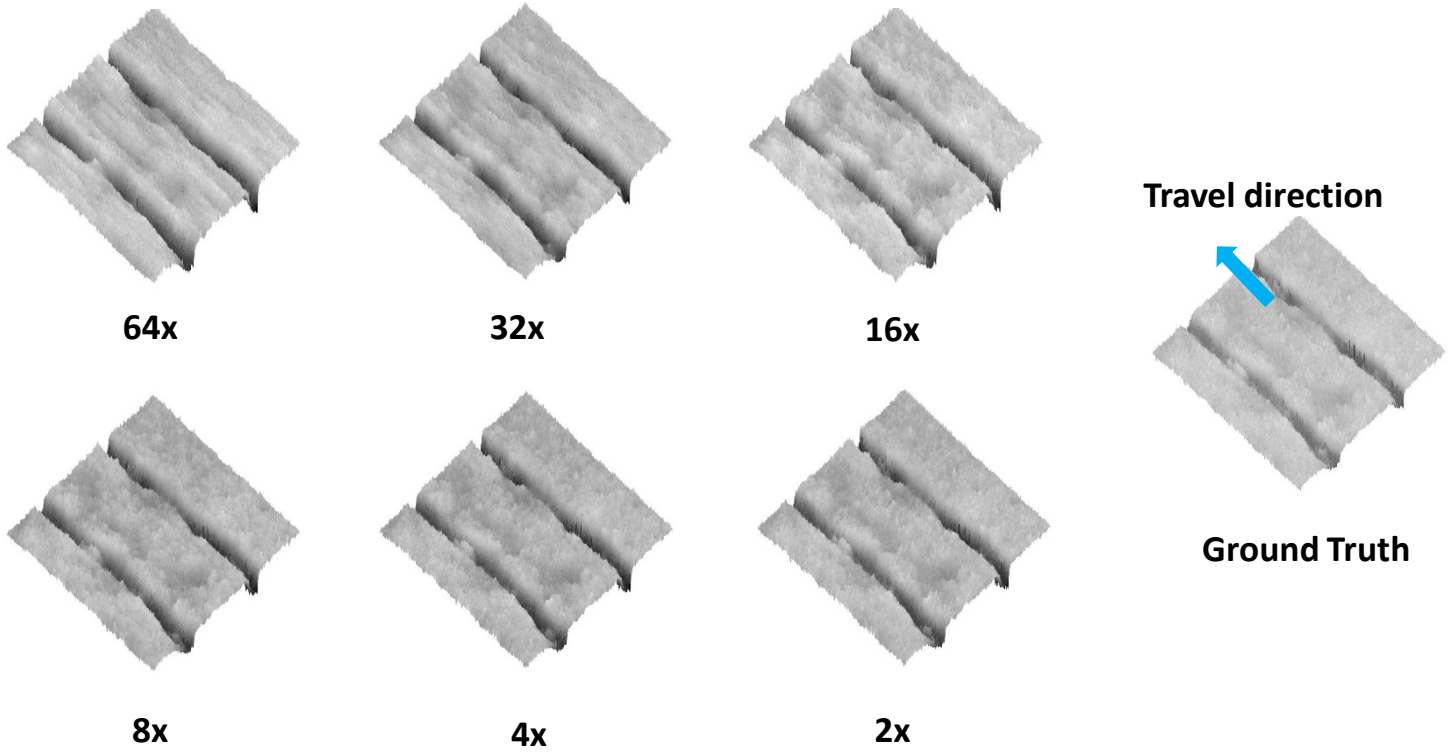
Example Results (1)

- Asphalt pavement

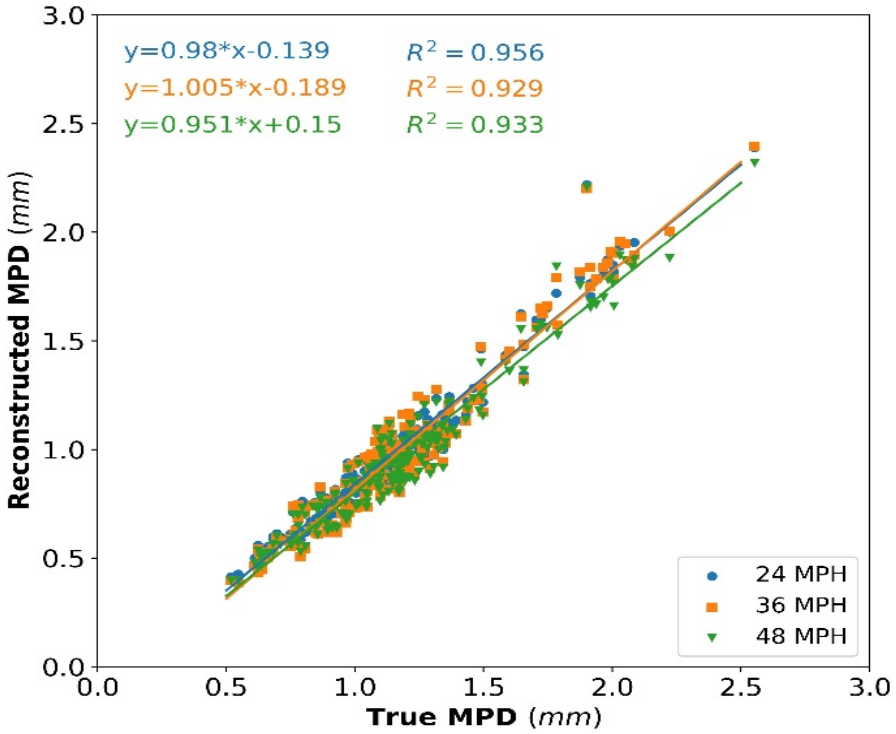


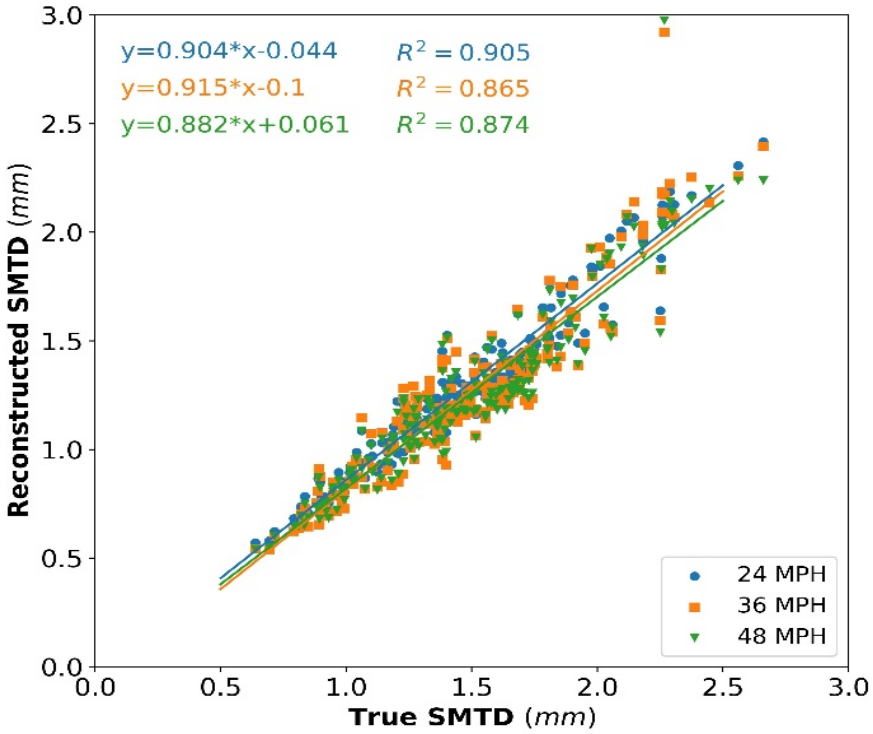
Example Results (2)

- Longitudinally grooved concrete

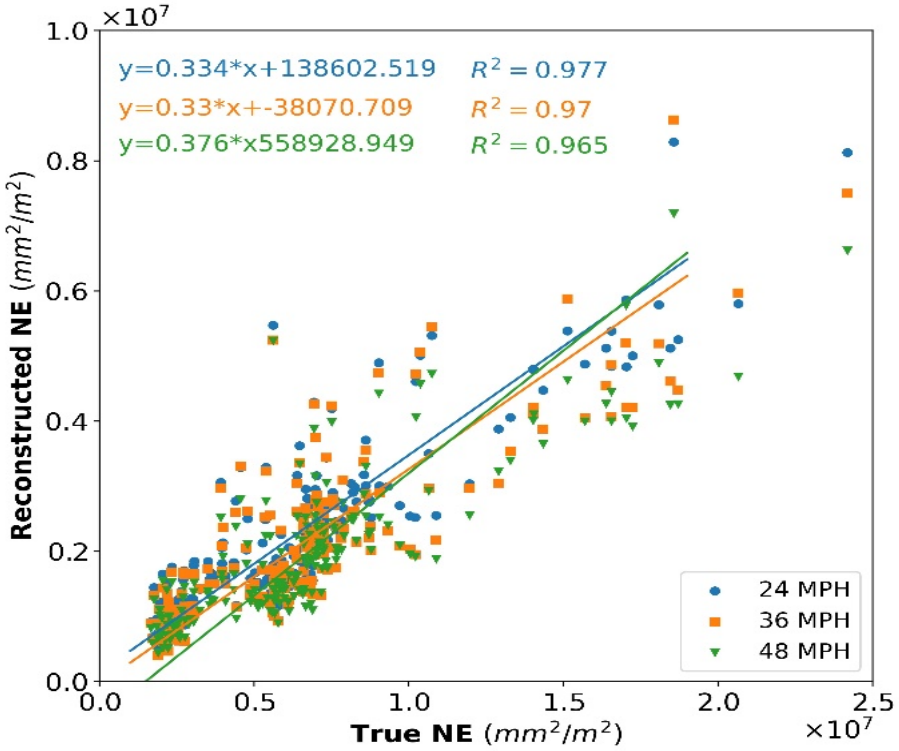


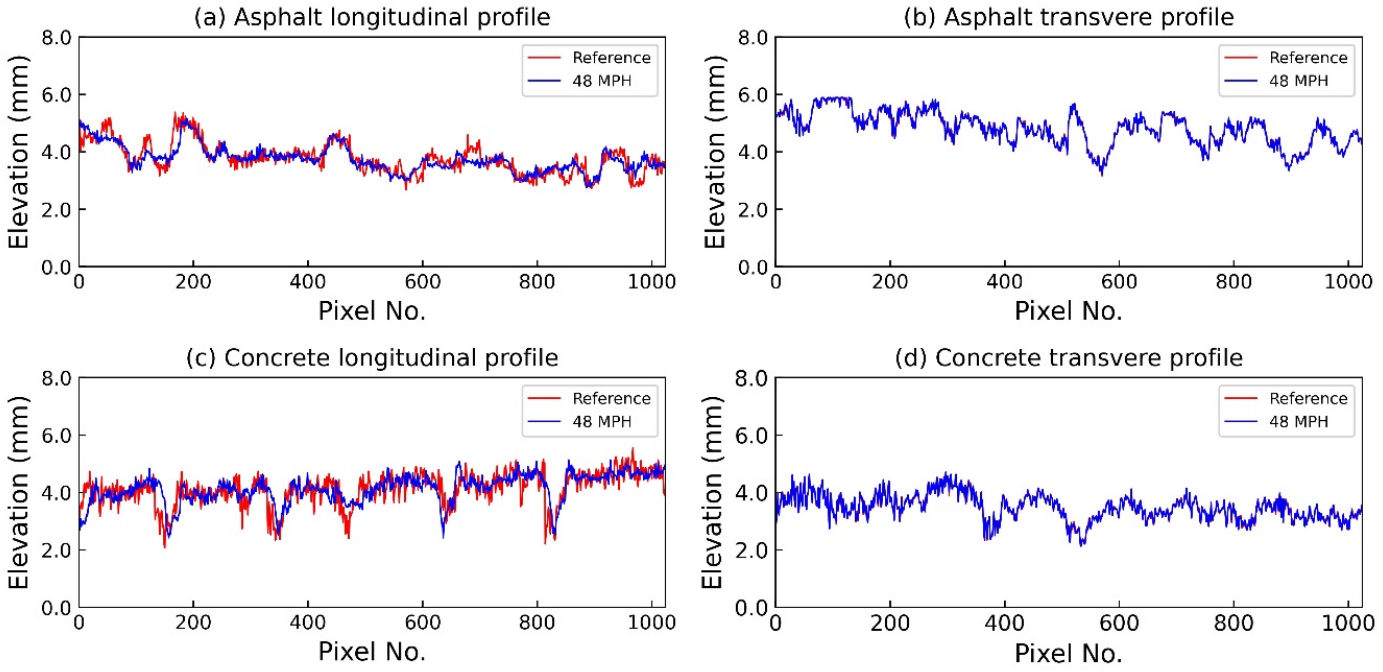
MPD and MTD for Macro-texture



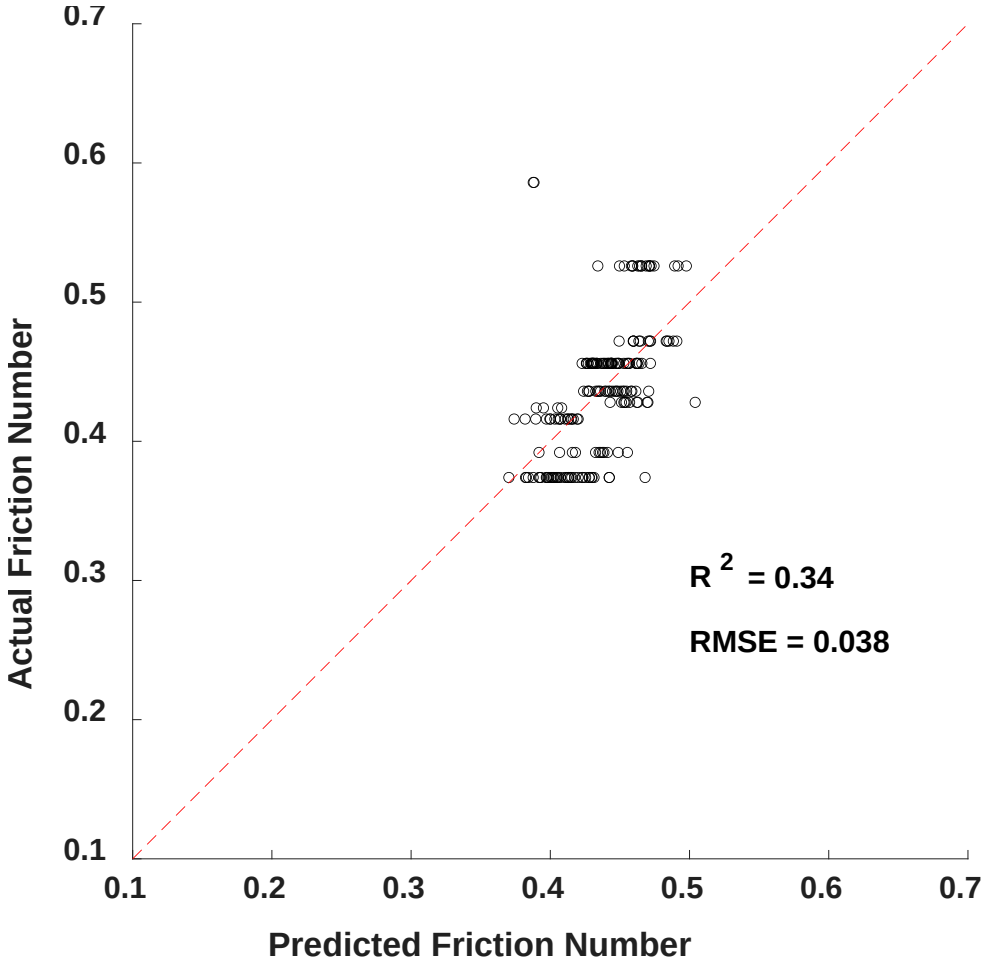


Wavelet Energy for Micro-Texture

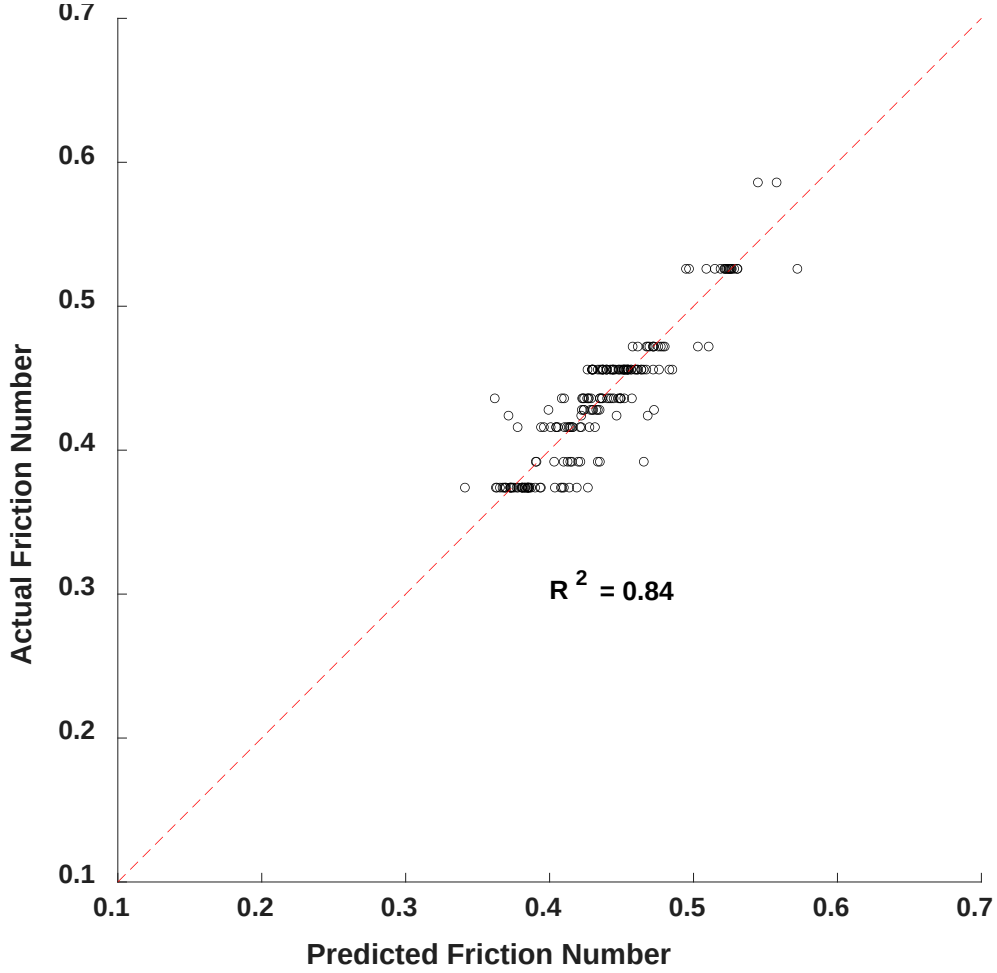




Pavement Friction Prediction - DFT



Multivariate Linear Regression Model



Neural Network Model

Conclusions

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Present

- **Deep Learning Outperforms Traditional Approaches**
- **Deep Learning Fulfills Pavement Distress Detection**
- **GPU Parallel Computing Supports Real-time & Faster Detection**

Future

- **Reduced Dependence on Manually-Labeled Data**
- **Multiple Distress Detection (pavements & bridges)**
- **ME-Design to PMS: Many AI Based Solutions**
- **Bright Future: Non-Contact 3D Safety Sensor**