

Imaging Techniques and Precision-Bias of Automated Cracking Detection for Airfield PCI

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Outline

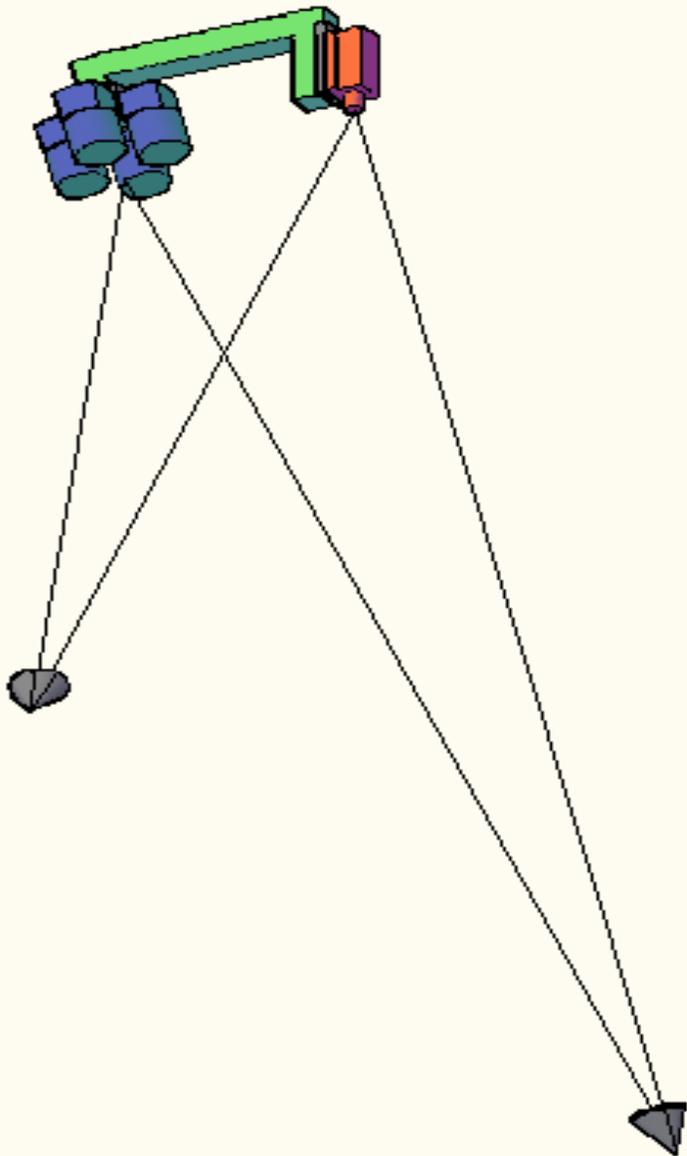
- PaveVision3D Ultra laser imaging technology
- 3D imaging processing algorithms and software solutions for automated PCI analysis (partial)
- Precision and bias evolution of software algorithms



PaveVision3D Ultra Systems



3D Ultra Data Collection System



PaveVision3D Ultra Approach

- Use Multiple Sensors
- Increase 3D Profile Line Rate to 30,000/second
- Complete Coverage of Pavement Lane
 - True 1mm at Any Data Collection Speed up to 60MPH (100KM/H)

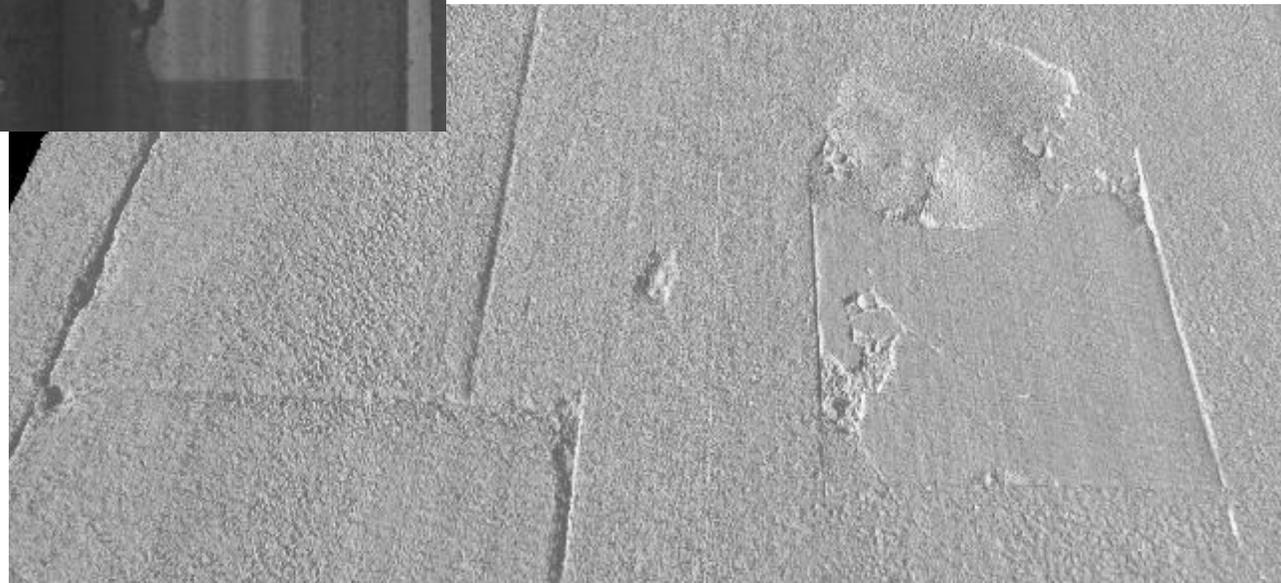


Virtual Pavement

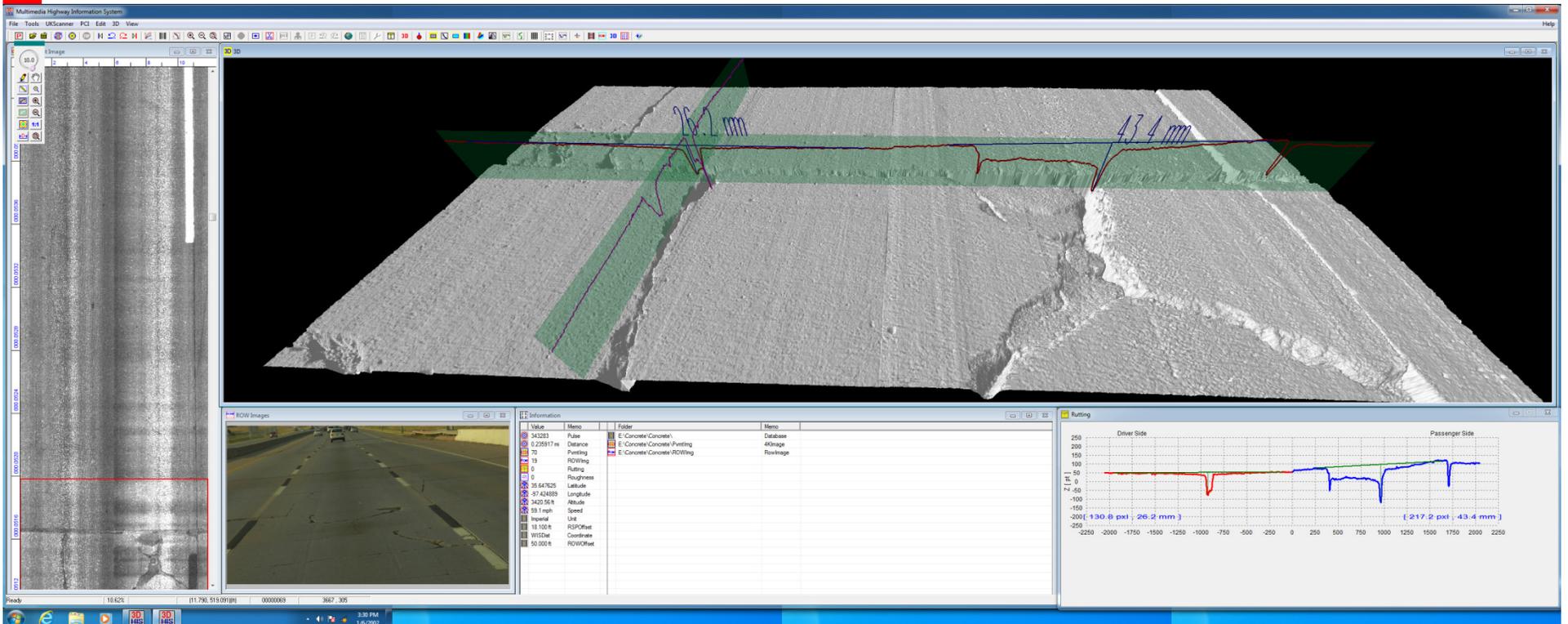
- 1mm Pavement Surface in All Three Dimensions
 - 0.33mm Resolution Vertically
- High-Precision IMU
- Result
 - Grades, Horizontal Curves, Cross-Slope



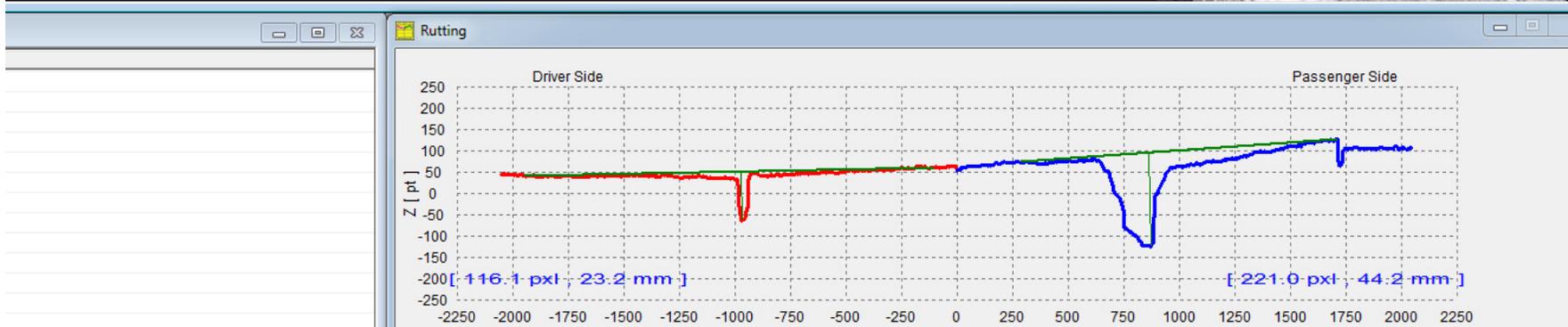
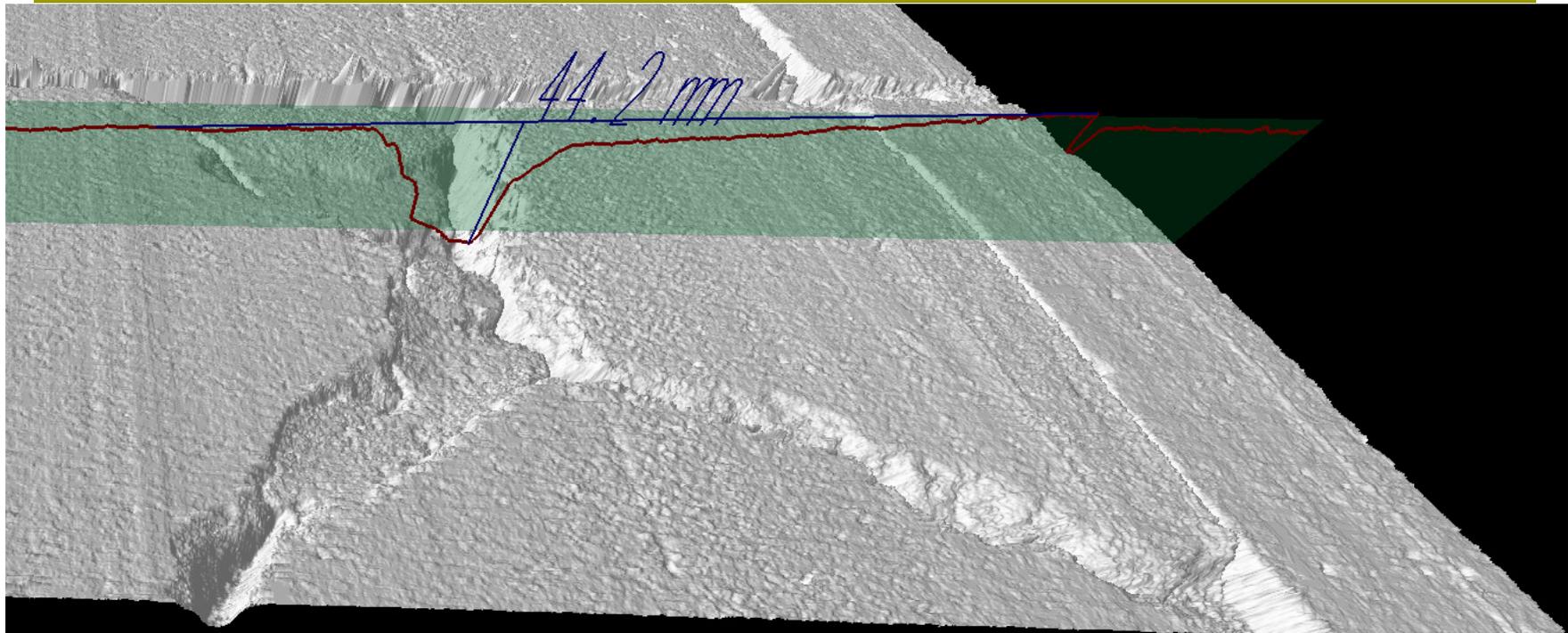
3D Ultra Data



3D Data at 60MPH (100KM/h)



3D Data at 60MPH (100KM/h)



Current Status

- Sensor Technology: Completed
- Challenges to the Team & Industry: Software Solutions
 - To be beautiful, & also usable to pavement engineers
 - Confidence in quality of data
 - Utilization & analysis of 1mm data



Data Analysis Challenges & Needs

- Fast data processing
- Robust algorithms
- Evaluation methods/protocols
- Algorithms to benchmark crack detection
 - Evaluation methods
 - Benchmark database



Big Data Challenges

- High Quality 3D Visualization
 - Big Data: 8 Million Pixels per Image which only Covers 2m-long Pavement Surface
 - Real-time Data Decompression
 - Real-time 3D Virtual Pavement Rendering
 - Real-time Analysis on Pavement Distresses
 - Detection
 - Classification
 - Measurement
 - Real Time Speed: Up to 60MPH
-

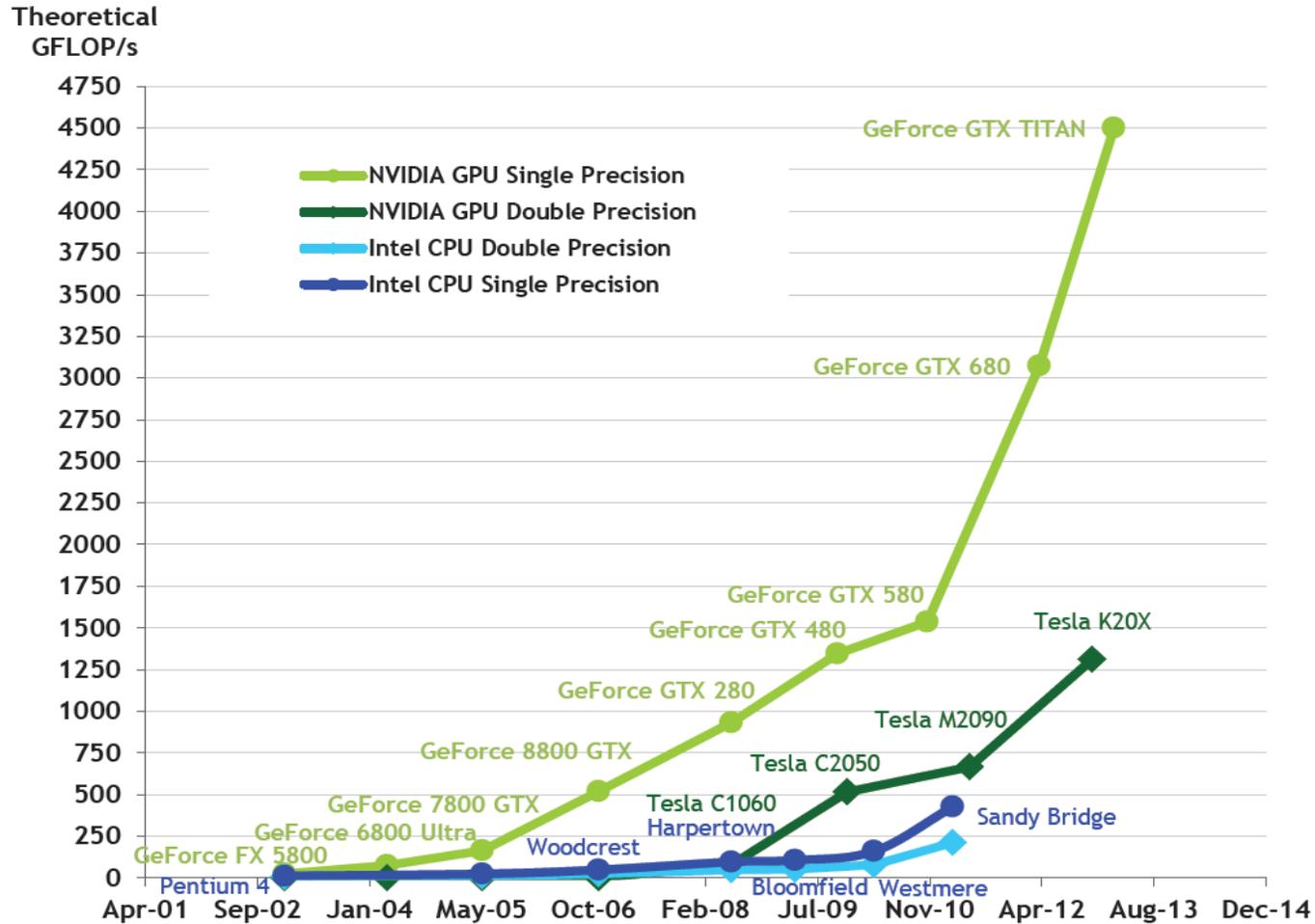


GPU & Parallel Computing

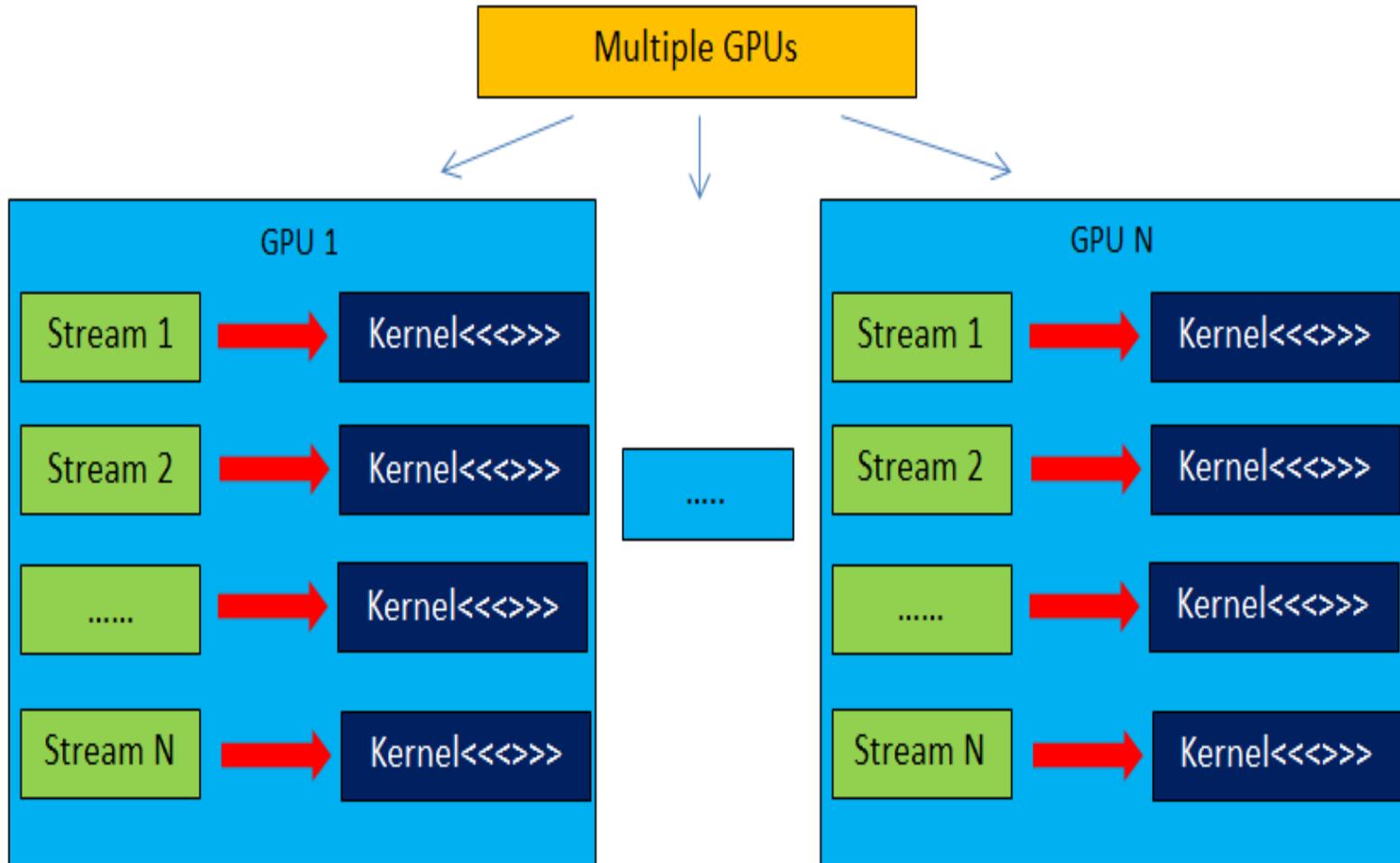
- Parallel computing
 - GPU computing
 - Multi-core
 - Streaming SIMD extensions
 - Multi-threading
- GPU computing
 - Millions of threads
 - Hundreds times faster than CPU
 - High independency of data
 - Data transfer between GPU and CPU



GPU and CPU (NVIDIA)

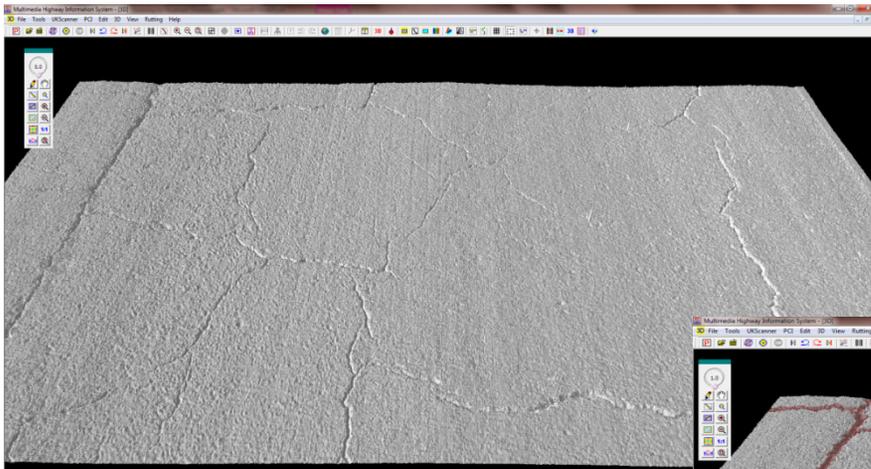


Multi-GPU Techniques

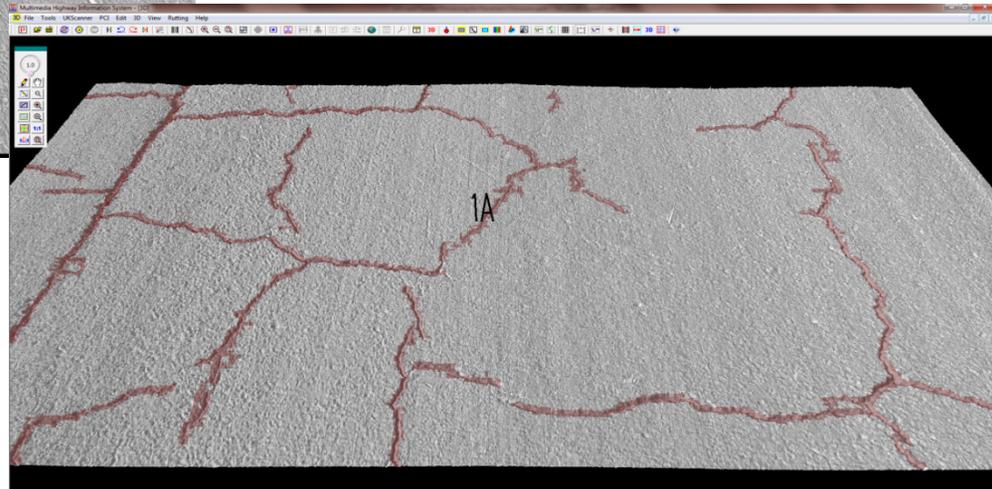


Automated Cracking Detection

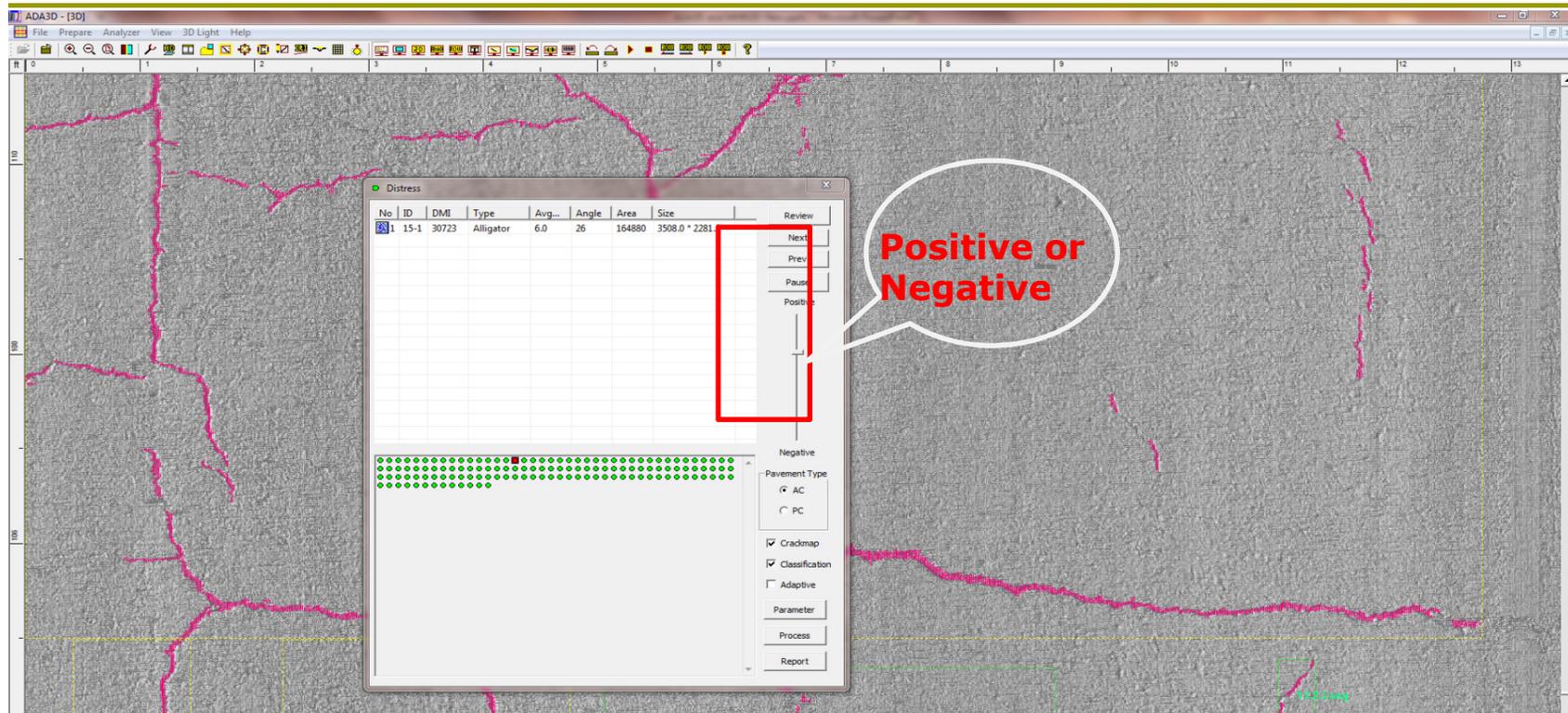
- Processing Time (Detection + Classification + Measurement):



- Parallel Techniques: **300ms**
- Single CPU: **20,000ms**

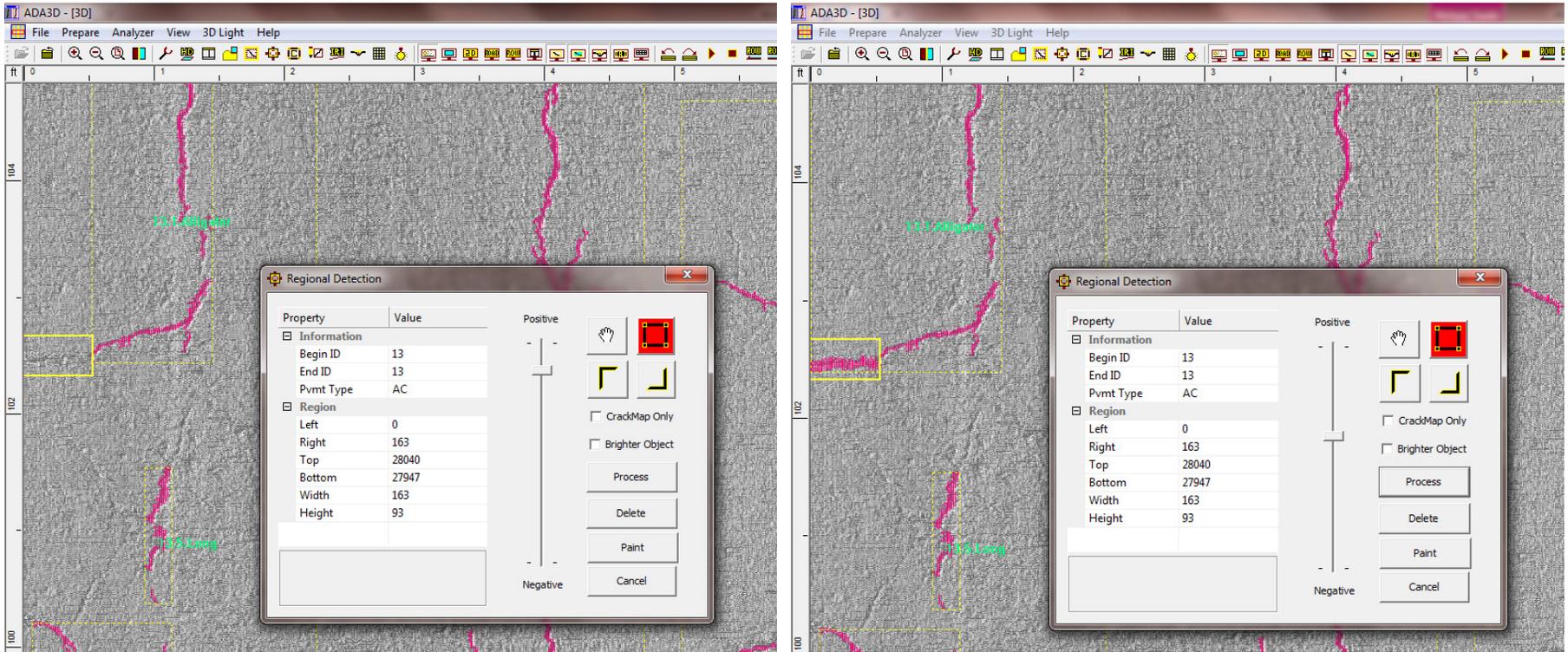


Interactive Cracking Detection



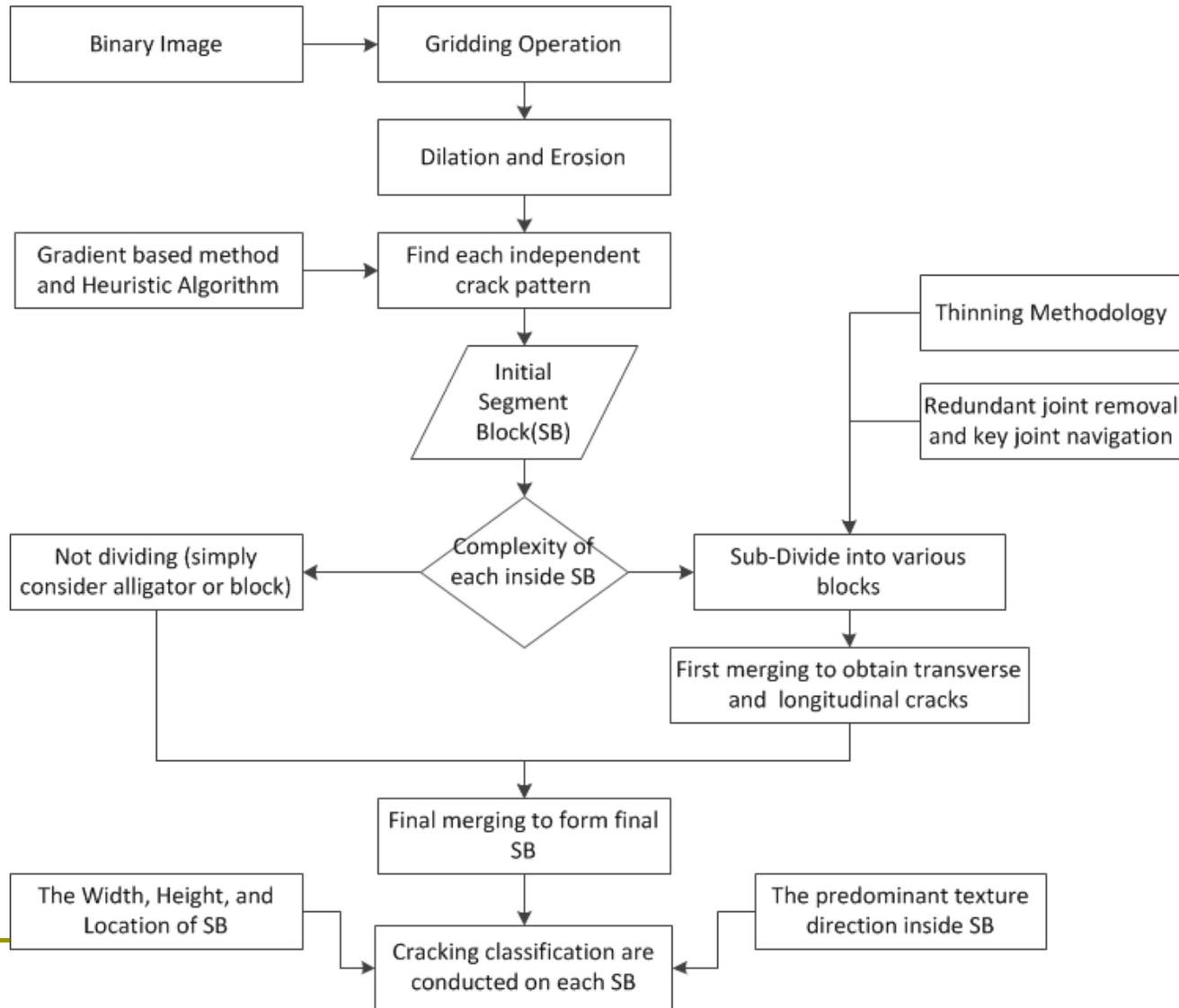
- ❑ Detection result: false-positive or false-negative
- ❑ Adjust level of contrast: achieve better performance

Regional Detection



- Help find fine cracks missed in automatic or interactive detection
- Delete false cracks within selected region

Crack Classification



Crack Classification: Preparation

- Meshing method
 - Accelerate processing speed and reduce noises
- Stitching disconnected cracks
 - Morphological filters: dilation & erosion techniques
 - Gradient based method: obtain close loop contour



Crack Classification: Contour

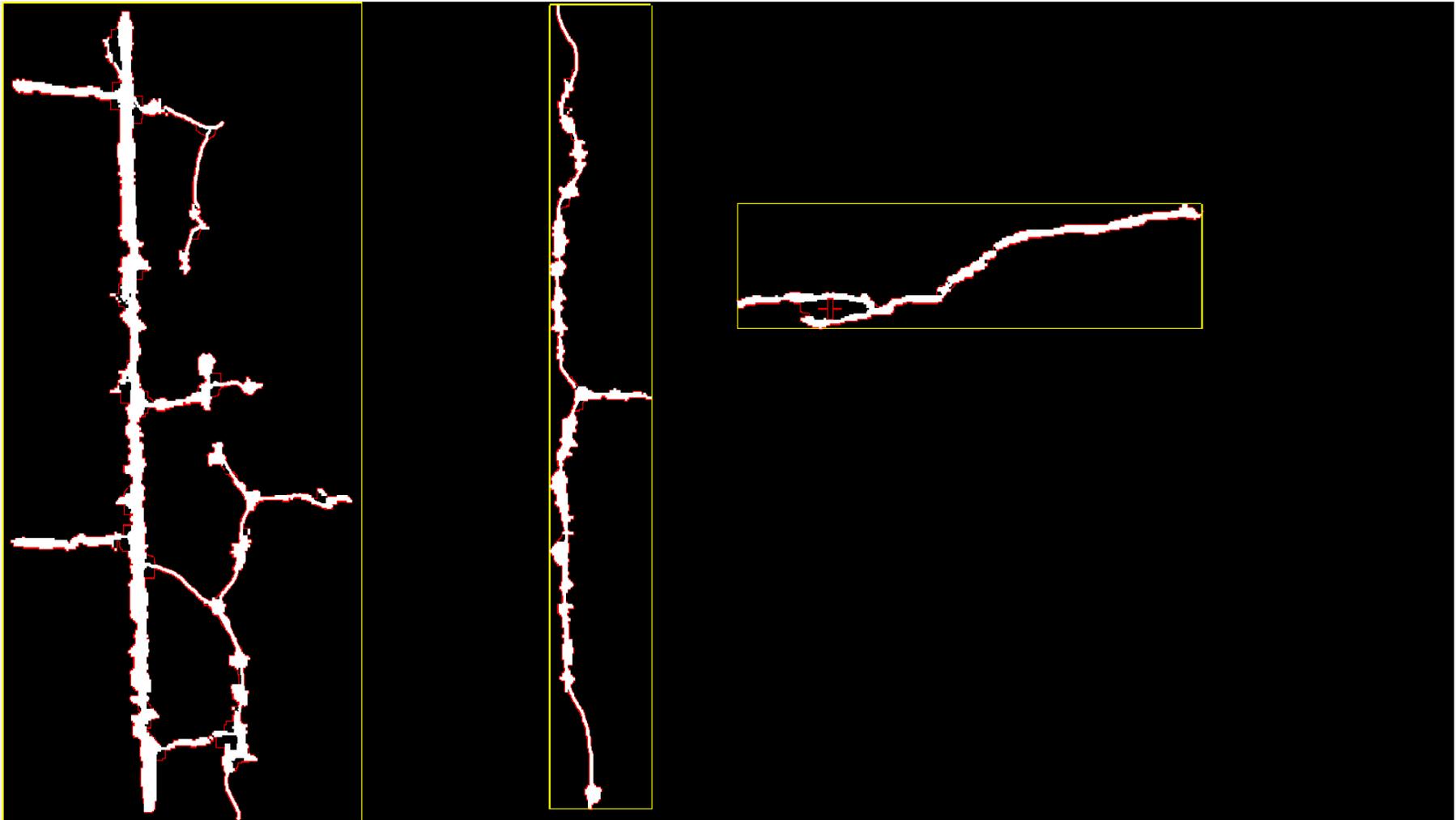


Crack Classification: Segmentation

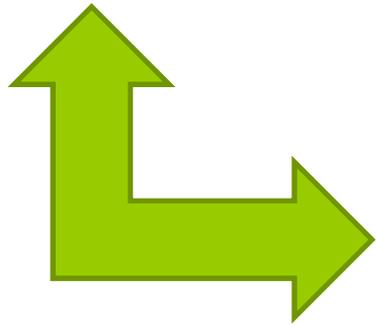
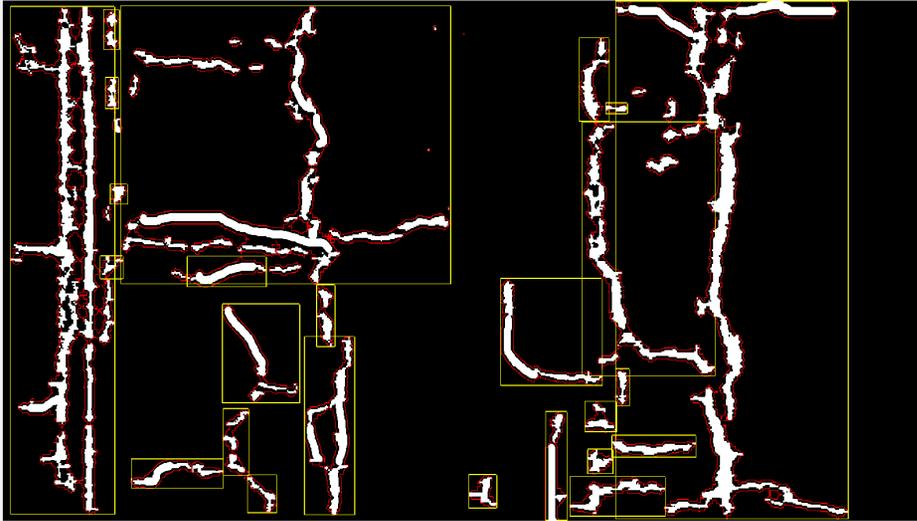
- Obtain contours of each close loop pattern
- Compute complexity of each segment block
- Apply thinning methods to subdivide segment blocks
- Apply merging methods to merge disconnected crack patterns



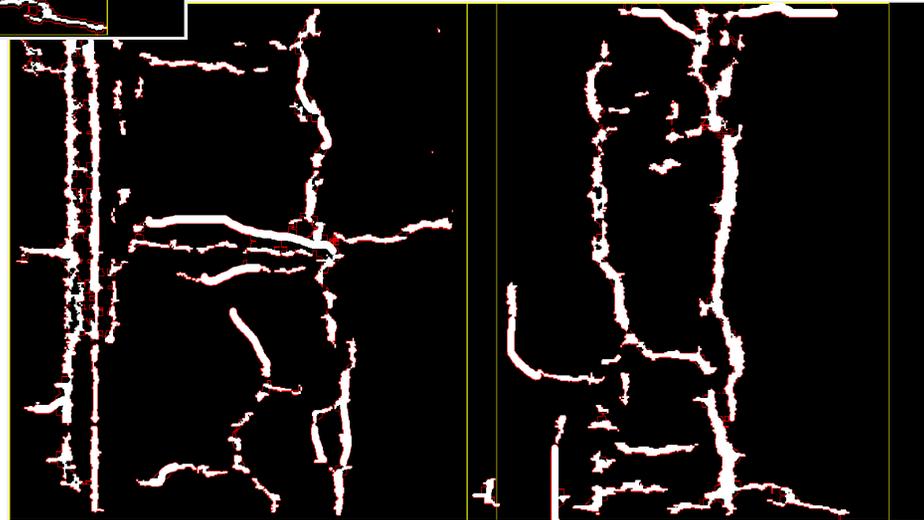
Classification Results: Segmentation



Classification Results: Segmentation



After merging

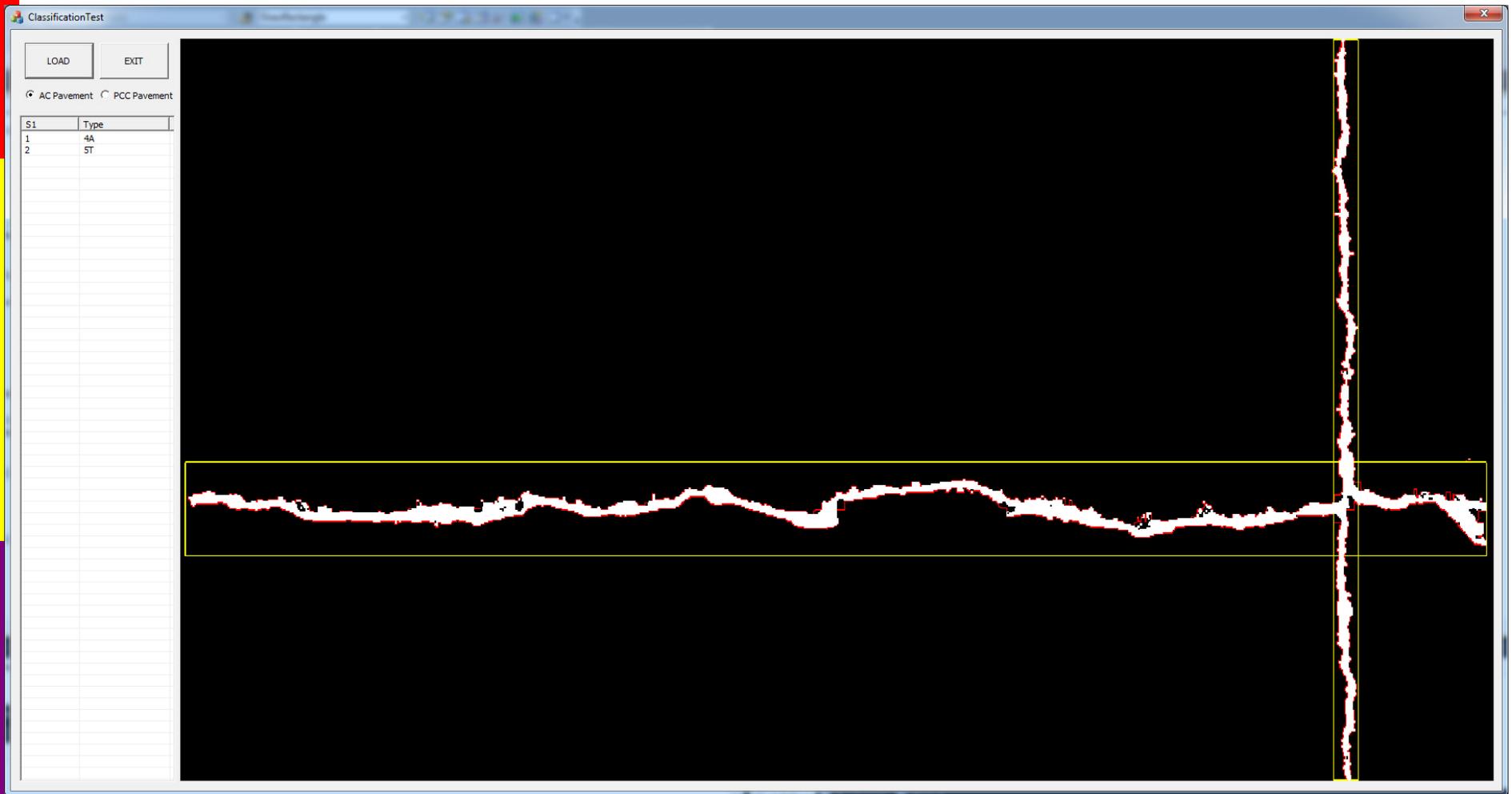


Crack Classification

- Calculate # of predominant crack direction
 - Complexity of crack pattern
 - Complex pattern: alligator or blocking
 - Simple pattern: transverse or longitudinal
- Combine geometric information with cracking pattern for classification
 - Location: WP, NWP
 - Width & height: segment block
 - # of predominant crack direction



Classification Results



Airport PCI Analysis

- ❑ PCI – Pavement Condition Index
- ❑ Quantitative Measure of Pavement Condition
- ❑ FAA AC 150/5380-6A (ASTM D5340-03)
- ❑ Pavement distress
 - Type
 - Quantity
 - Severity
- ❑ Objective and repeatable



Airfield PCI Issues in APMS

- Difficulty in PCI Calculation
 - Tedious manual rating processes
 - Substantial manpower
 - Access to airfield pavement
- Difficulty in Preparing Maintenance Programs Using PCI only
 - Short of detailed quantitative information

(Source: Margaret Broten and Rachel De Sombre (2001). *The Airfield Pavement Condition Index (PCI) Evaluation Procedure: Advantages, Common Misapplications, and Potential Pitfalls*. 5th International Conference on Managing Pavements, Seattle, Washington)



Benchmarking Crack Detection

- Distress detection algorithms
 - Fast
 - Achieve high scores in both precision and recall rate
- Crack image library for benchmarking of crack detection algorithms



Precision Recall Analysis

- Precision: correctly identified cracks over total identified cracks
- Recall: correctly identified cracks over total crack
- Confusion Matrix

	Actual positive	Actual negative
Predicted positive	True Positive	False Positive
Predicted negative	False Negative	True Negative



Precision Recall Analysis

		actual value		total
		p	n	
prediction outcome	p'	True Positive	False Positive	P'
	n'	False Negative	True Negative	N'
total		P	N	

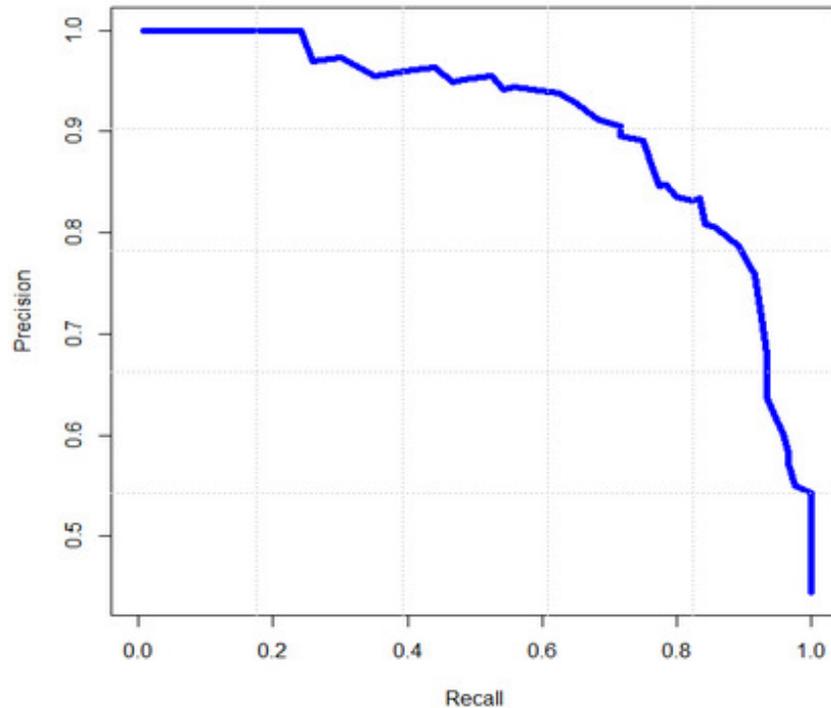
$$\text{Precision} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Positive}}$$

$$\text{Recall} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}}$$

$$F = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

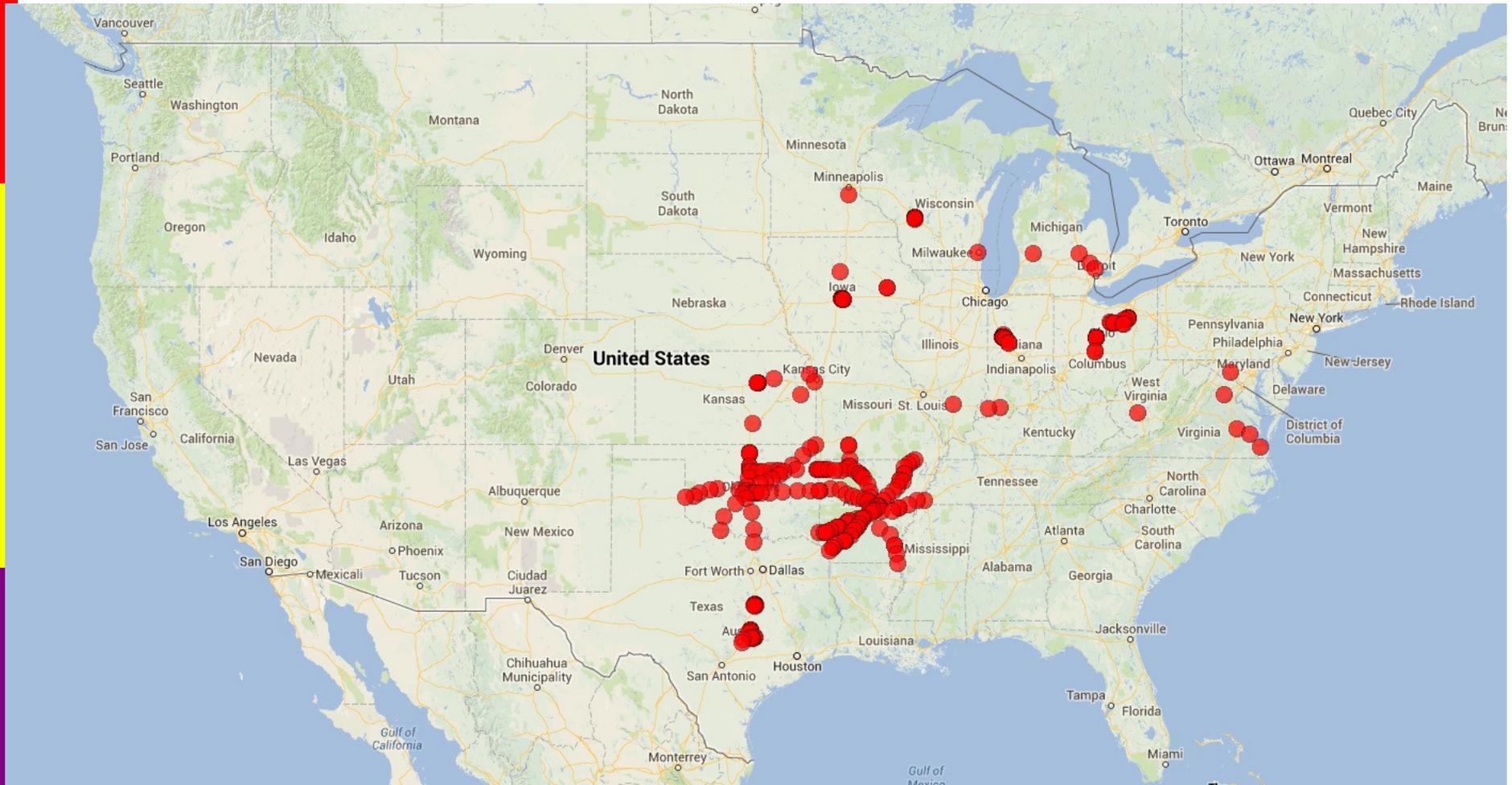
Precision-Recall (PR) Curve

Precision as Y axis; Recall as X axis



- Trade-off Relationship
- Upper Right Corner

Benchmark Image Sources



3D Benchmark Image Library

- Total size: 1535
- Image Group:
 - Flexible Pavement: 4
 - Rigid Pavement: 4
 - High Friction Surface
- Ground truth Generation
 - Crack map images
 - Manual visual inspection



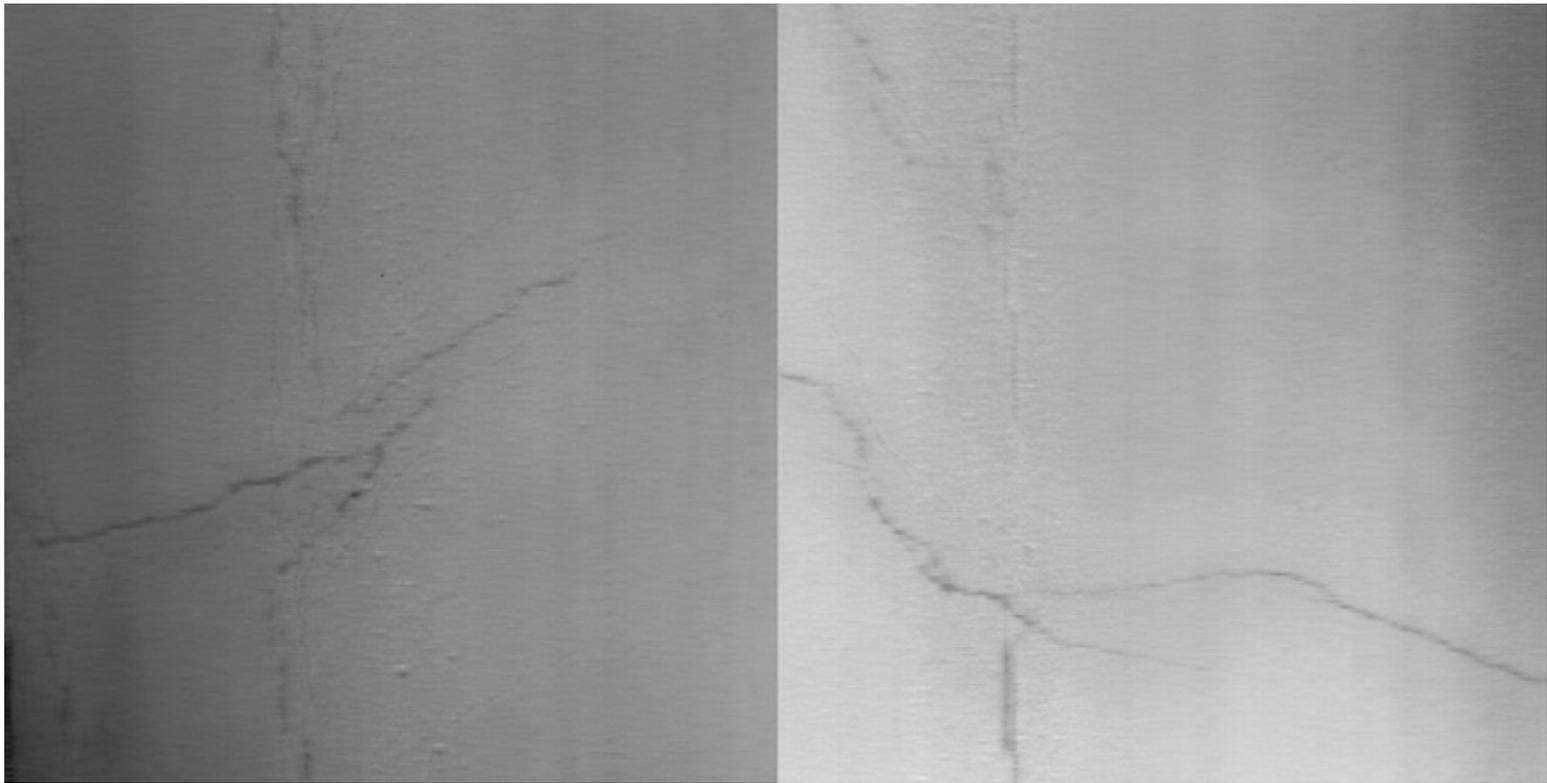
3D Benchmark Image Library

Group	Flexible Pavement				High Friction
	Coarse Surface	Good Quality	Bad Quality	Crack Sealing	
Size	224	255	260	80	61
Group	Rigid Pavement				
	Complex Condition	Good Condition	Texture Pavement	NGCS	
Size	260	285	120	51	



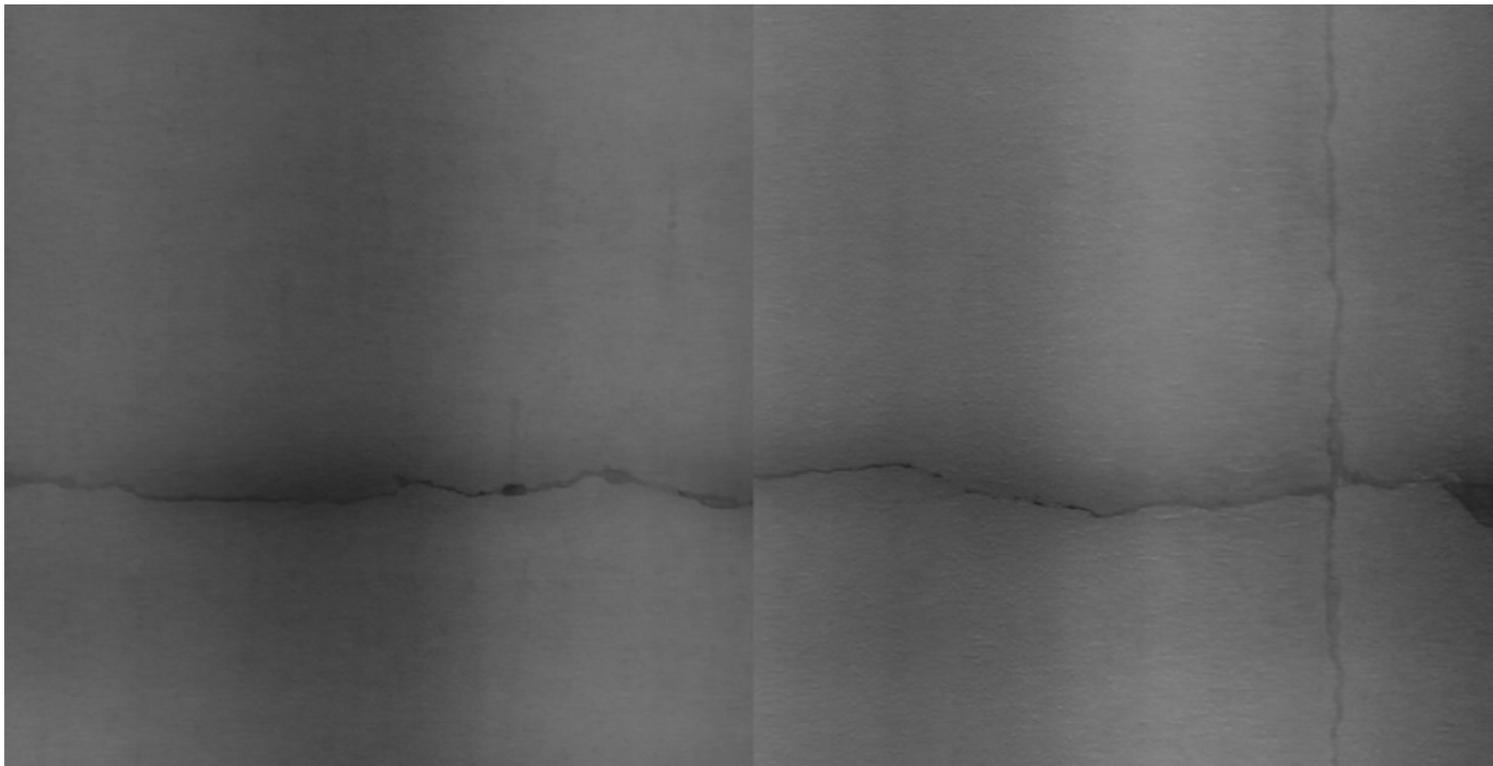
Example Image

- Asphalt Bad Quality



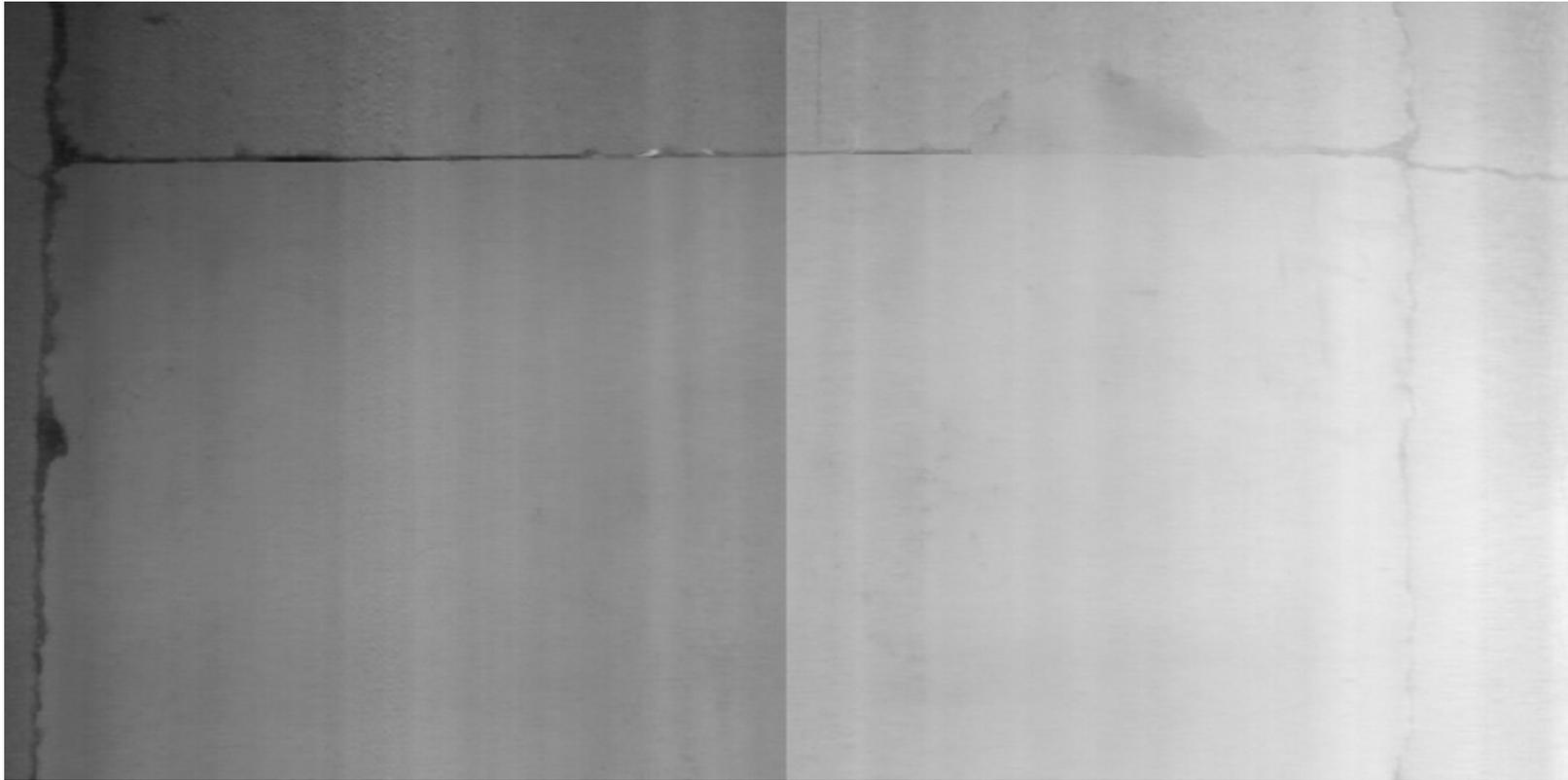
Example Image

- Asphalt Good Quality

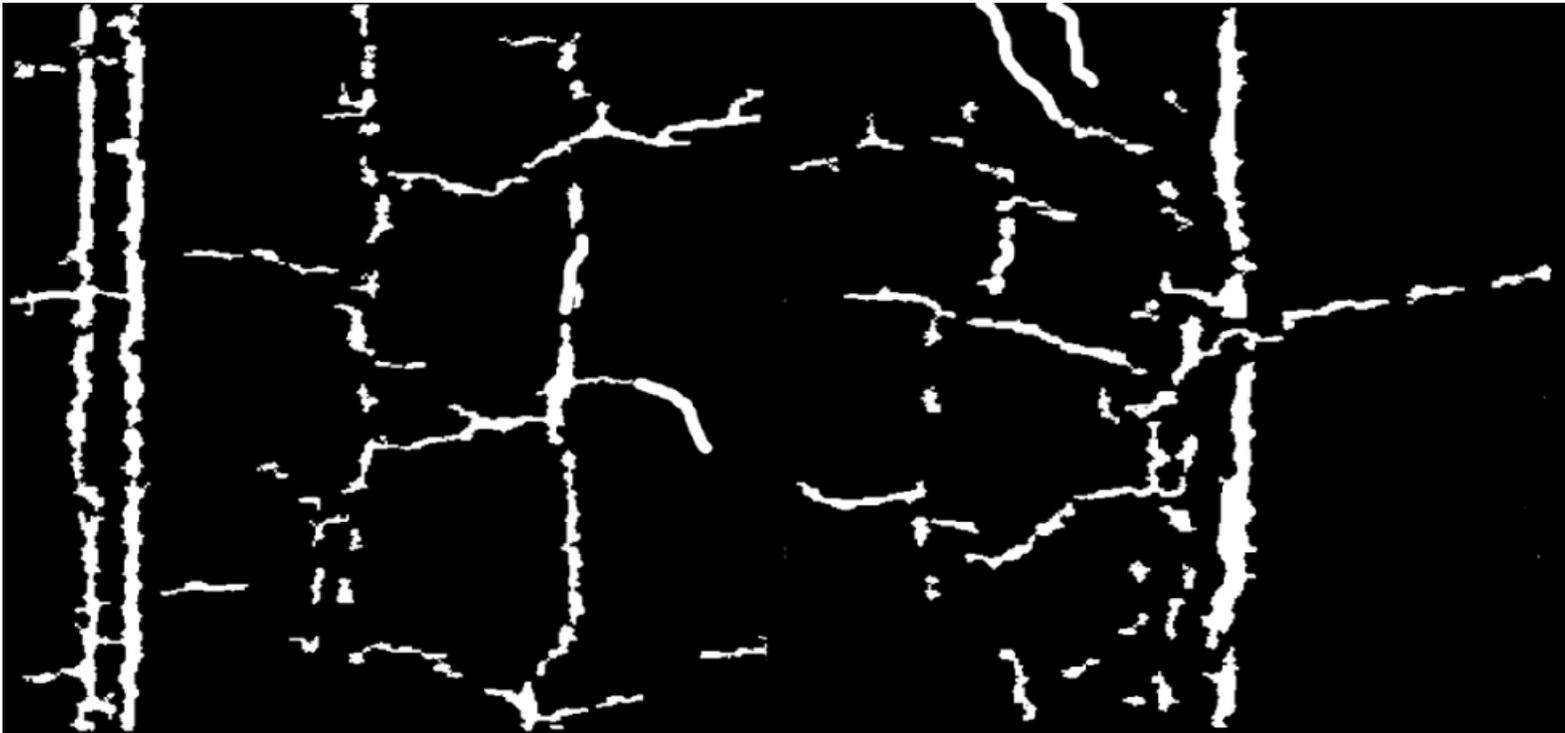


Example Image

- Concrete Complex Condition

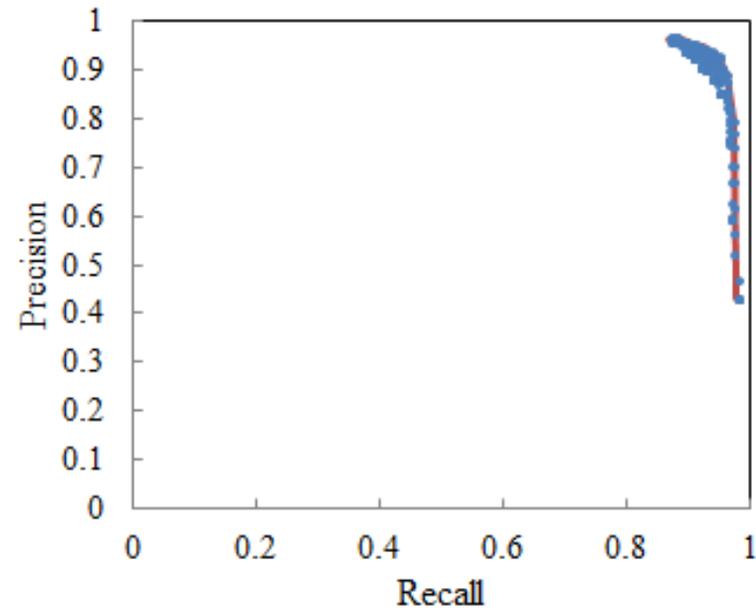
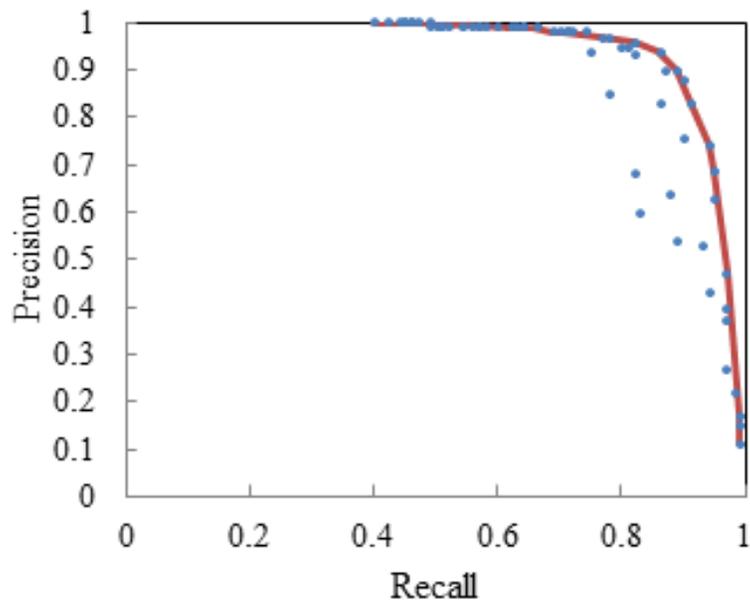


Ground Truth Labeling



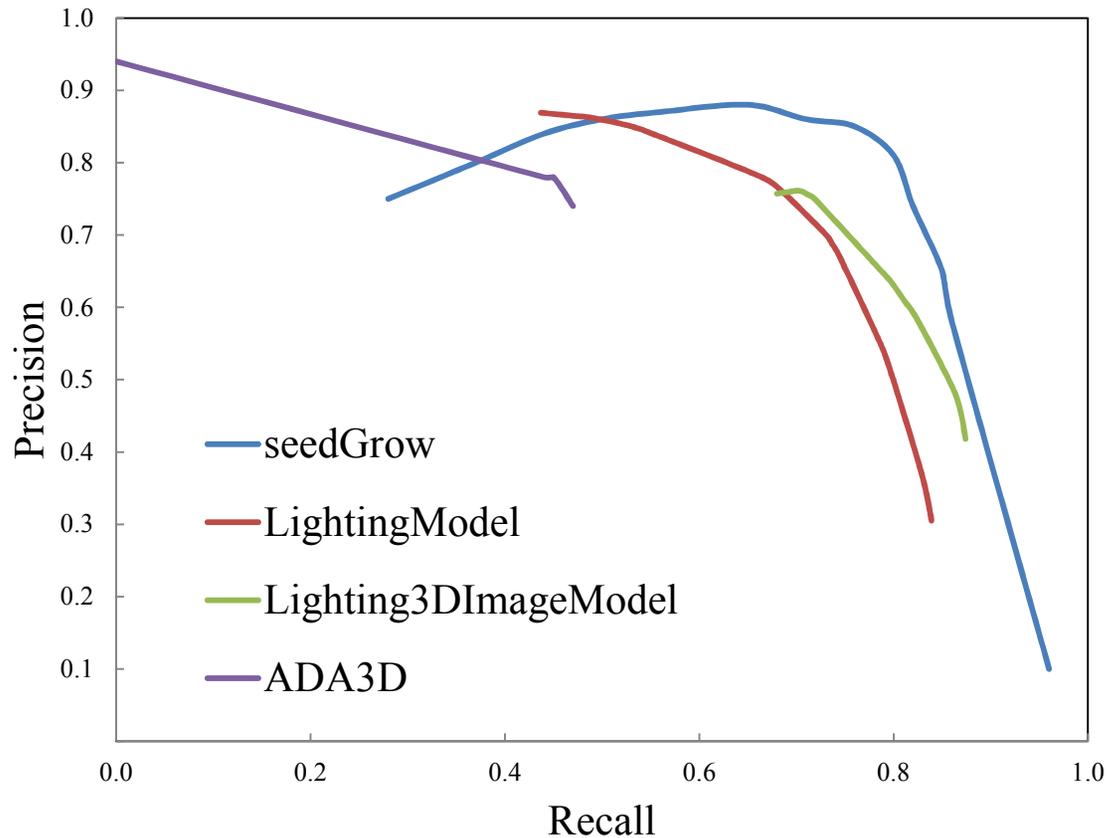
Case Study

- Performance
- Sensitivity



Algorithm Performance Analysis

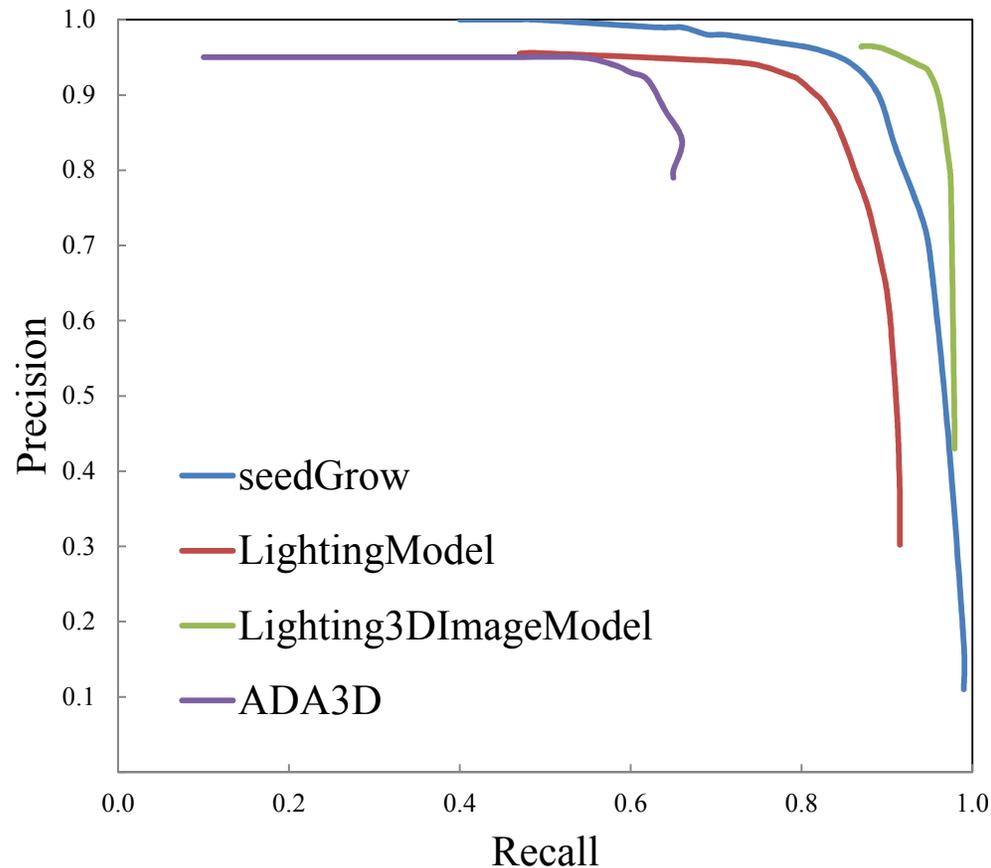
Asphalt Bad Quality



Method	F-value
SeedGrow	0.80
Lighting Model	0.72
Lighting 3D Image Model	0.73
ADA3D	0.56

Algorithm Performance Analysis

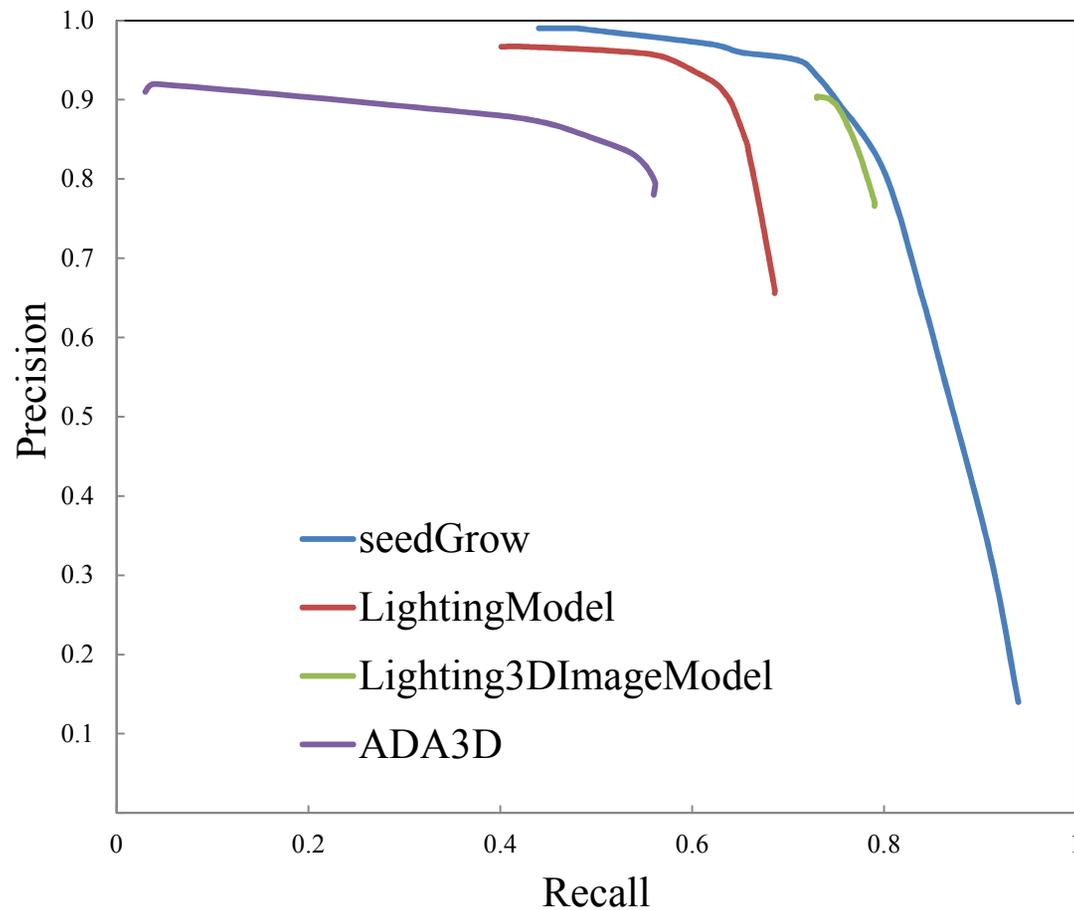
□ Asphalt Good Quality



Algorithm	F-value
SeedGrow	0.90
Lighting Model	0.86
Lighting 3D Image Model	0.94
ADA3D	0.74

Algorithm Performance Analysis

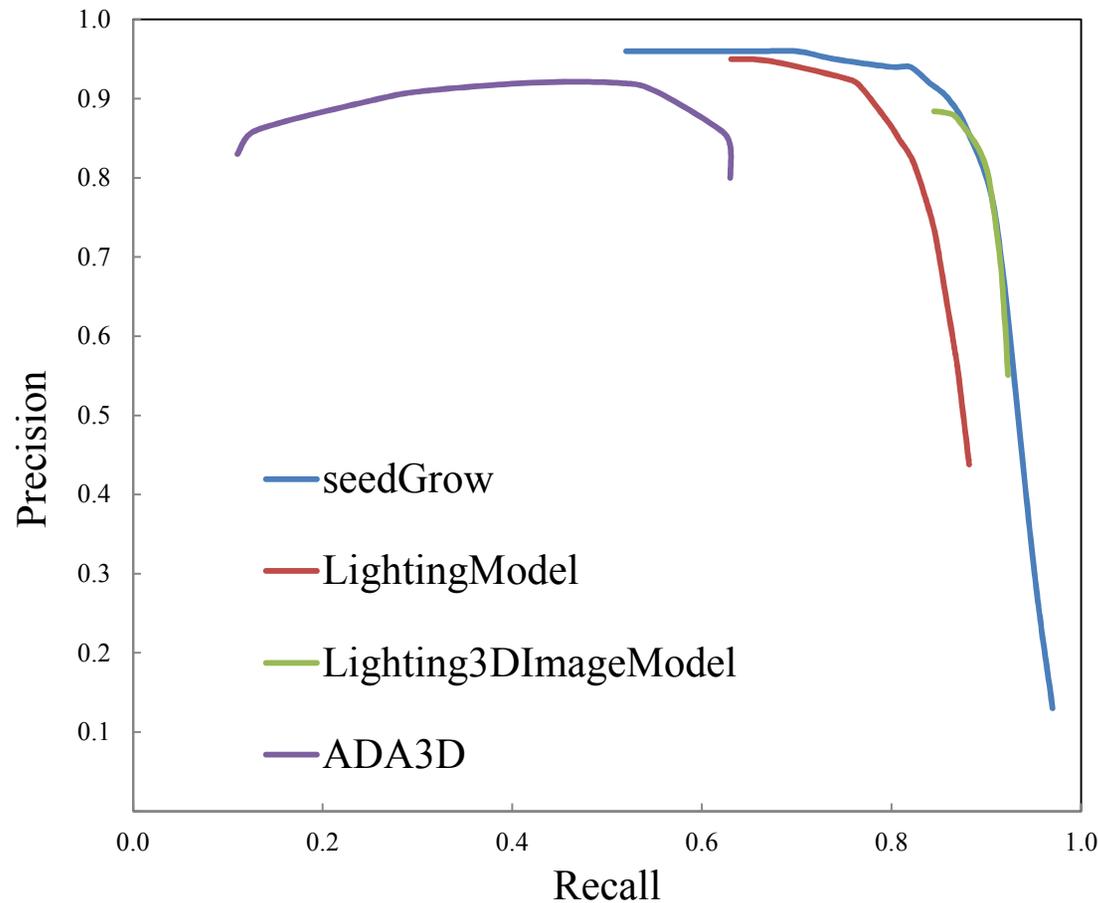
Concrete Complex Condition



Test	F-value
SeedGrow	0.82
Lighting Model	0.72
Lighting 3D Image Model	0.80
ADA3D	0.66

Algorithm Performance Analysis

Concrete Good Condition



Test	F-value
SeedGrow	0.88
Lighting Model	0.82
Lighting 3D Image Model	0.86
ADA3D	0.72

Algorithm Performance (F Score)

Test Group	SeedGrow	Lighting Model	Lighting 3D Image Model	ADA3D
Asphalt Bad Quality	0.80	0.72	0.73	0.56
Asphalt Good Quality	0.90	0.86	0.94	0.74
Concrete Complex Condition	0.82	0.72	0.80	0.66
Concrete Good Condition	0.88	0.82	0.86	0.72
Average	0.85	0.78	0.83	0.67

SeedGrow > Lighting 3D > Lighting Model > ADA3D



Sensitivity Analysis

- Calculate SD of discrete PR points from top 40% F score.

$$SD = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{X})^2}{n} + \frac{\sum_{i=1}^n (y_i - \bar{Y})^2}{n}}$$

Test Group	SeedGrow	Lighting Model	Lighting 3D Image Model	ADA3D
Asphalt Bad Quality	0.092	0.062	0.015	0.021
Asphalt Good Quality	0.069	0.062	0.020	0.032
Concrete Complex Condition	0.058	0.049	0.008	0.018
Concrete Good Condition	0.053	0.034	0.017	0.020
Average	0.068	0.052	0.015	0.023

Lighting 3D < ADA3D < Lighting Model < SeedGrow

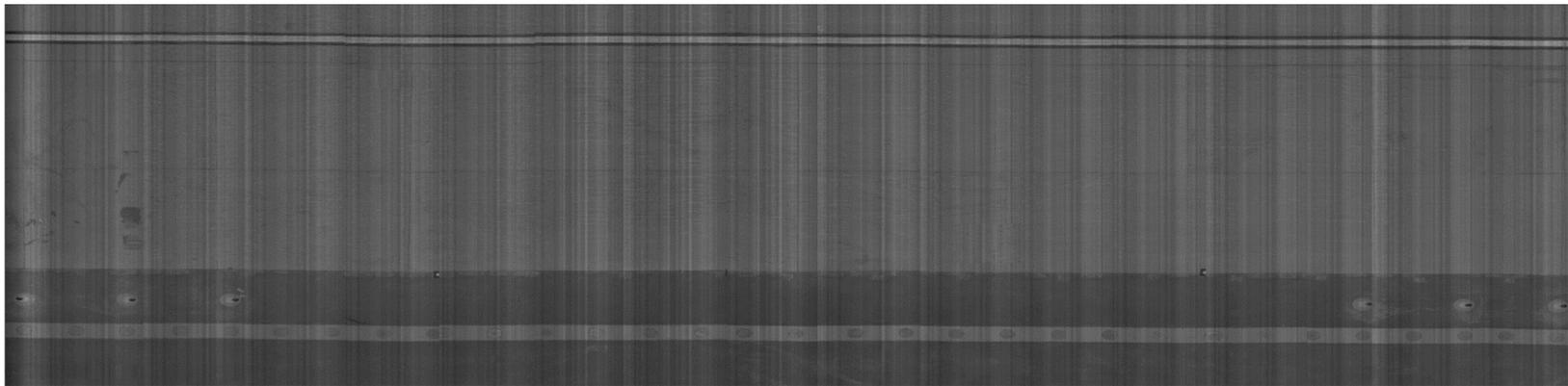
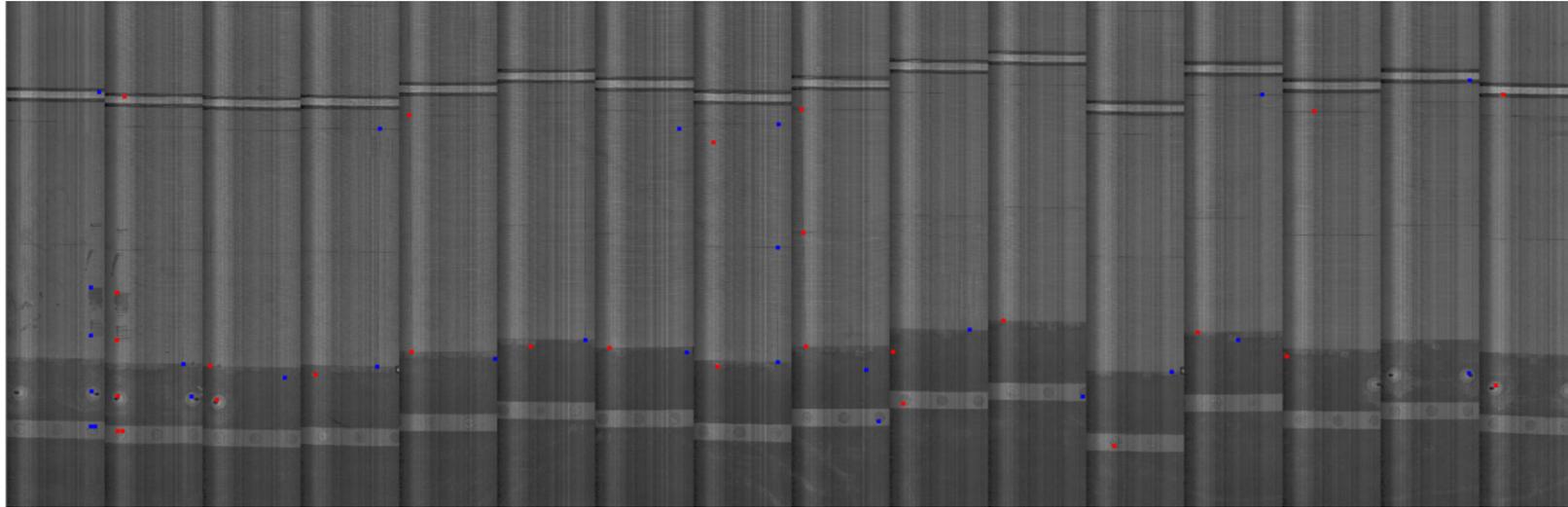


What's Next?

- ❑ Improve the efficiency of stitching and develop 3D virtual runway with attached detailed distress information in database
- ❑ Implement automated capabilities for PCI analysis (partial)
- ❑ Achieve acceptable levels of precision, bias and repeatability



Stitching Images



MHIS-Airport2D

Runway

Information

Grid Ratio (v.r.) 1.2

No	TimeCode	Road
0	20090327.034206.203	AT
1	20090327.034039.640	AT
2	20090327.033859.390	AT
3	20090327.033704.234	AT
4	20090327.033525.812	AT
5	20090327.033334.843	AT
6	20090327.033207.343	AT
7	20090327.033035.468	AT
8	20090327.032901.093	AT
9	20090327.032734.359	AT
10	20090327.032602.781	AT
11	20090327.032429.937	AT
12	20090327.032304.140	AT
13	20090327.032138.859	AT
14	20090327.032013.890	AT
15	20090327.031826.671	AT
16	20090327.031703.625	AT
17	20090327.031533.843	AT
18	20090327.031417.296	AT
19	20090327.031251.828	AT
20	20090327.031130.187	AT
21	20090327.030957.515	AT
22	20090327.030822.484	AT
23	20090327.030703.125	AT
24	20090327.030523.609	AT
25	20090327.030404.687	AT

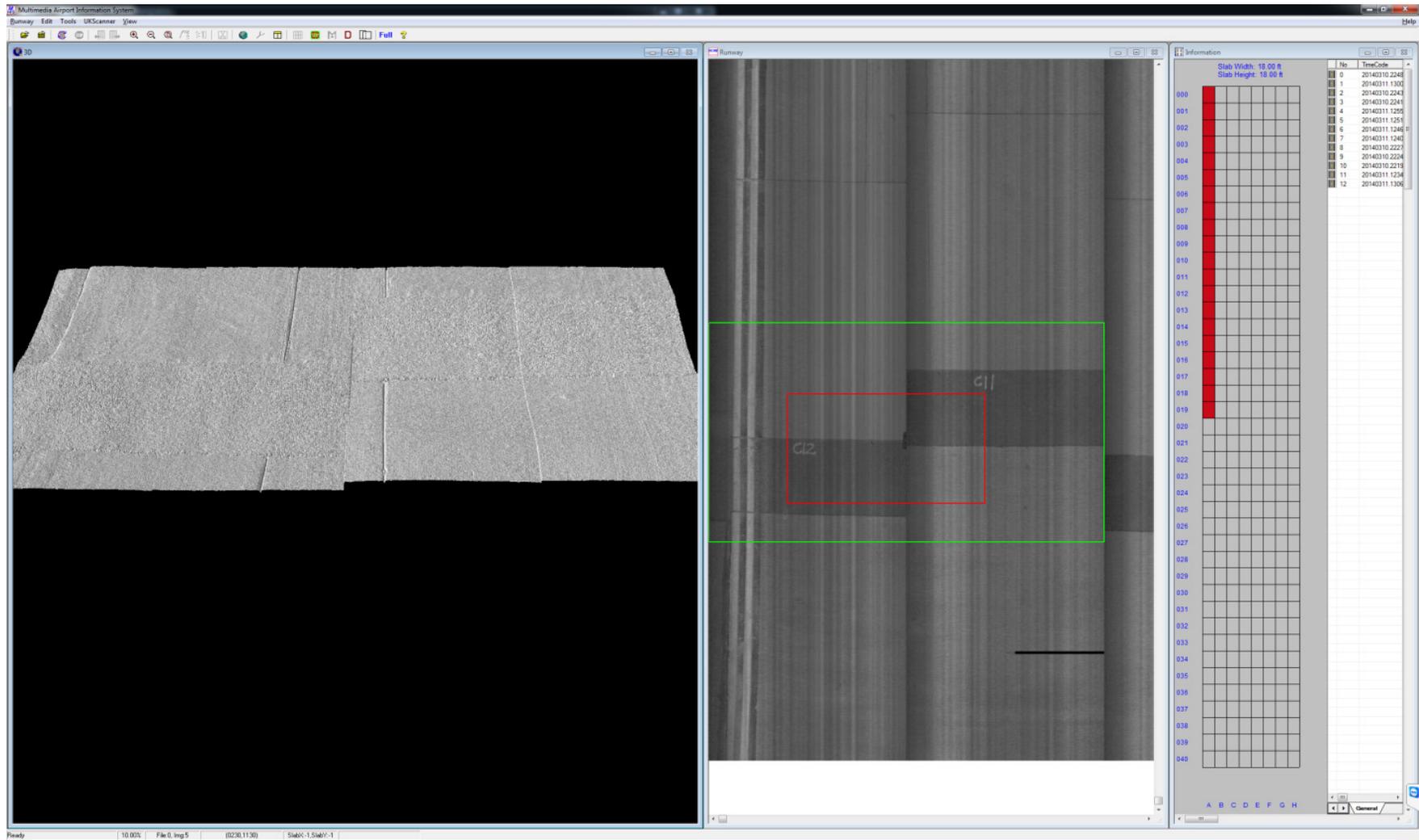
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A B C D E F G H I J

General Distress Sample



MHIS-Airport3D Interface



Questions ?

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