A Sensor-Based and Spatially Enabled Roadway Asset Management System

(A Reliable, Cost-effective Performance Measurement Technology)

James Tsai, Ph.D., P.E., Associate Professor (Presenter)
Co-PI: **Zhaohua Wang**, Ph.D., Senior Research Engineer
Feng Li, Ph.D. Candidate
Chengbo Ai, Ph.D. Candidate

Georgia Institute of Technology

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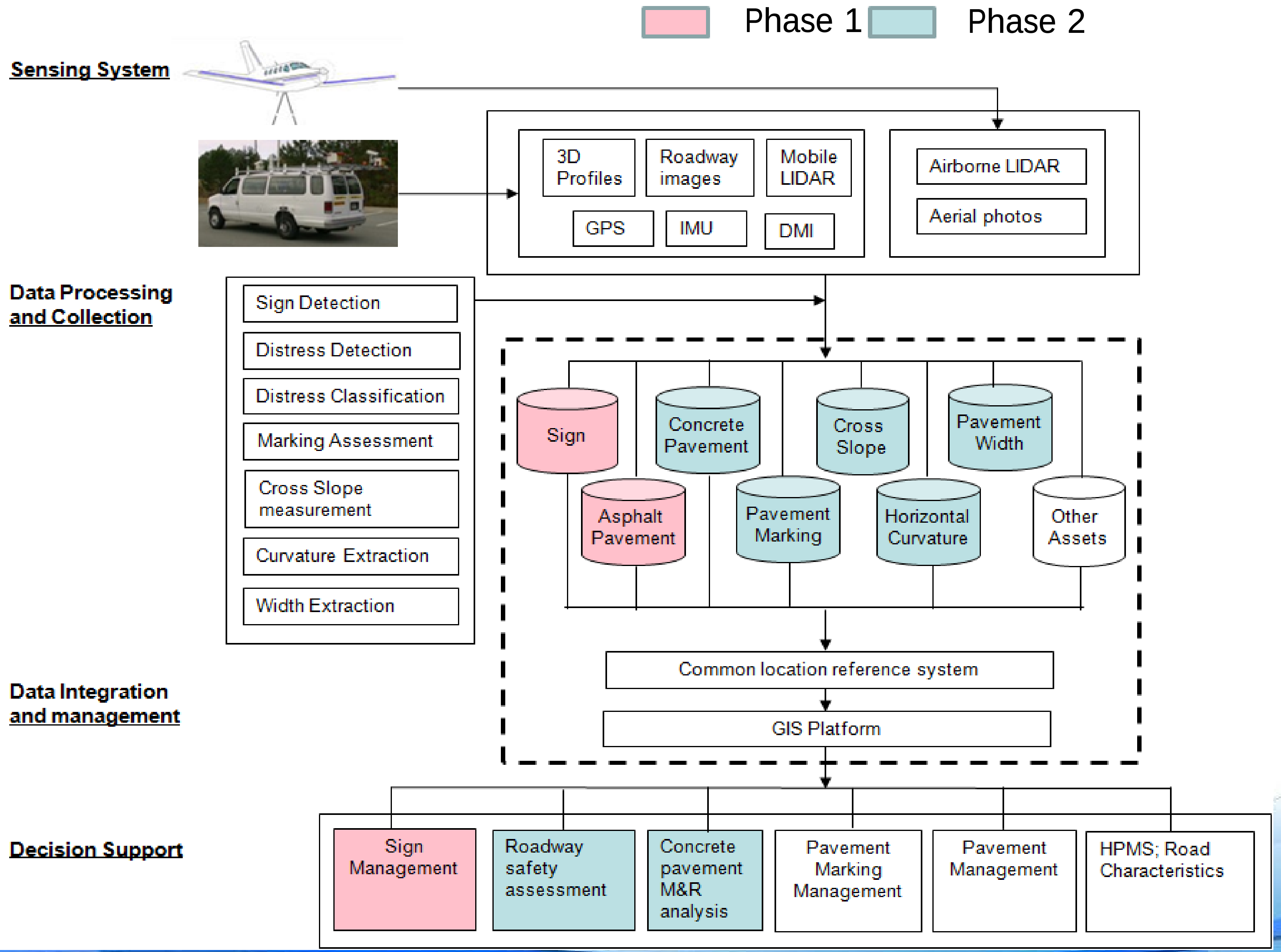
Outline

- Introduction
  - Architecture of A Sensor-Based and Spatially Enabled Roadway Asset Management System
  - Research objective
  - Research focuses
- Georgia Tech Sensing Vehicle
- Pavement rutting/crack
- Traffic sign
- Summary

A Sensor-Based and Spatially Enabled Roadway Asset Management System



Research Objective

- To develop and validate an innovative and cost-effective means to inventory roadway assets and evaluate their condition (e.g. asphalt pavement surface conditions and traffic signs).

A Reliable and Cost-effective Measurement Technology

Research Roadmap and Focuses in Phase 1

Integration of Sensing Devices

- LCMS (for pavement asset)
- Imaging and mobile LiDAR (for traffic sign asset)

Data Collection

- Agencies’ data
- Sensing device collected data

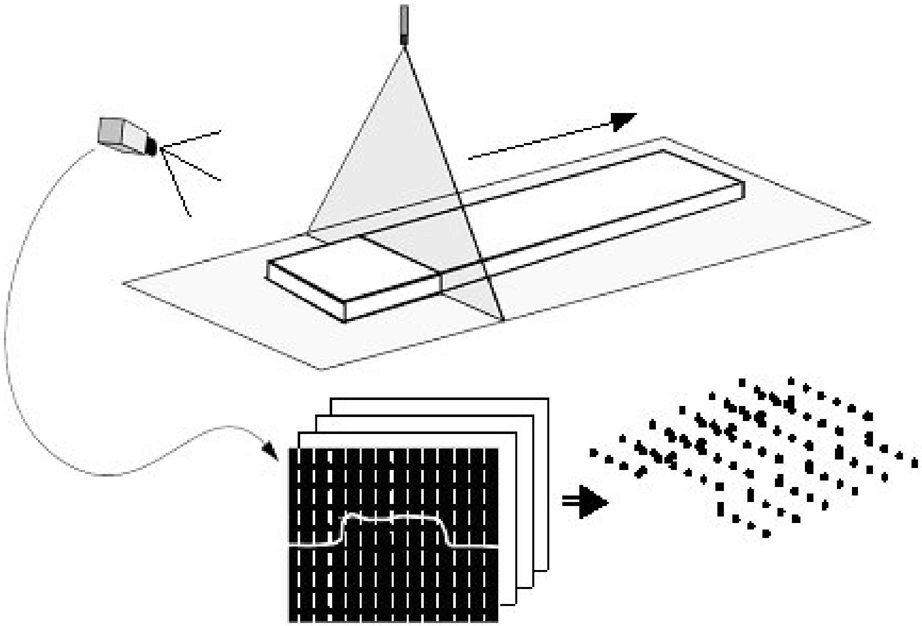
Application Validation (Seven Focuses)

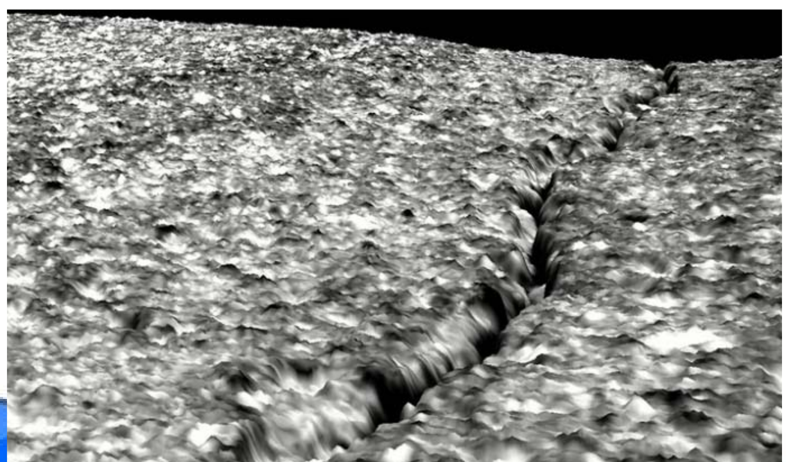
1. Network-level rutting measurement
2. Localized rutting identification
3. Performance evaluation of automatic crack detection algorithms
4. Validation of crack detection using 3D continuous transverse profiles
5. Develop and validate an enhanced sign inventory procedure using mobile-LiDAR and image processing technology
6. Validate the sign condition assessment using mobile LiDAR
7. Validate an integrated GIS-based sign asset management system

Outreach Plan

Georgia Tech Sensing Vehicle (All-In-One Technology)

3D Line Laser Imaging Technology





1. Transverse dir : 1 mm

2. Elevation: 0.5 mm

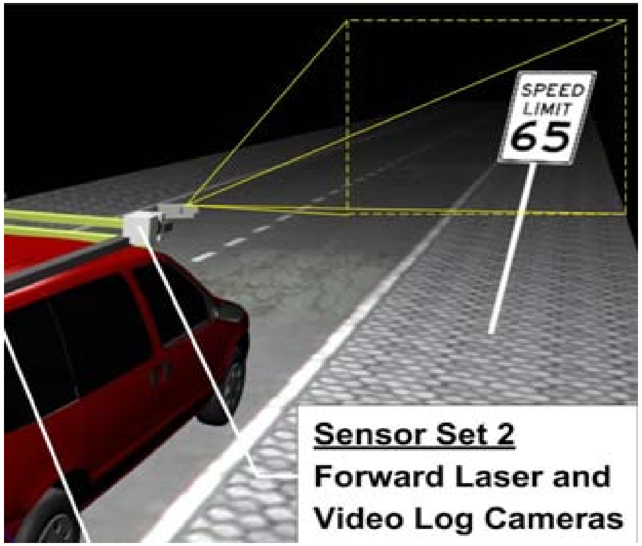
3. Data points collected per second and width covered:

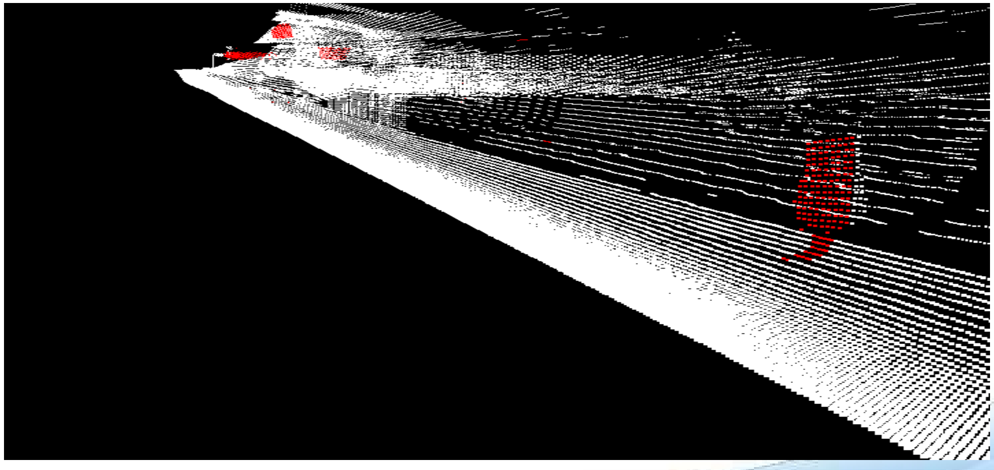
2 (lasers) * 2048 (points/profile/laser) * 5600 HZ = 22,937,600 points

2 (lasers) * 2048 (points/profile/laser) * 1 (mm) = 4.096 m

LiDAR and Imaging System

High resolution LiDAR

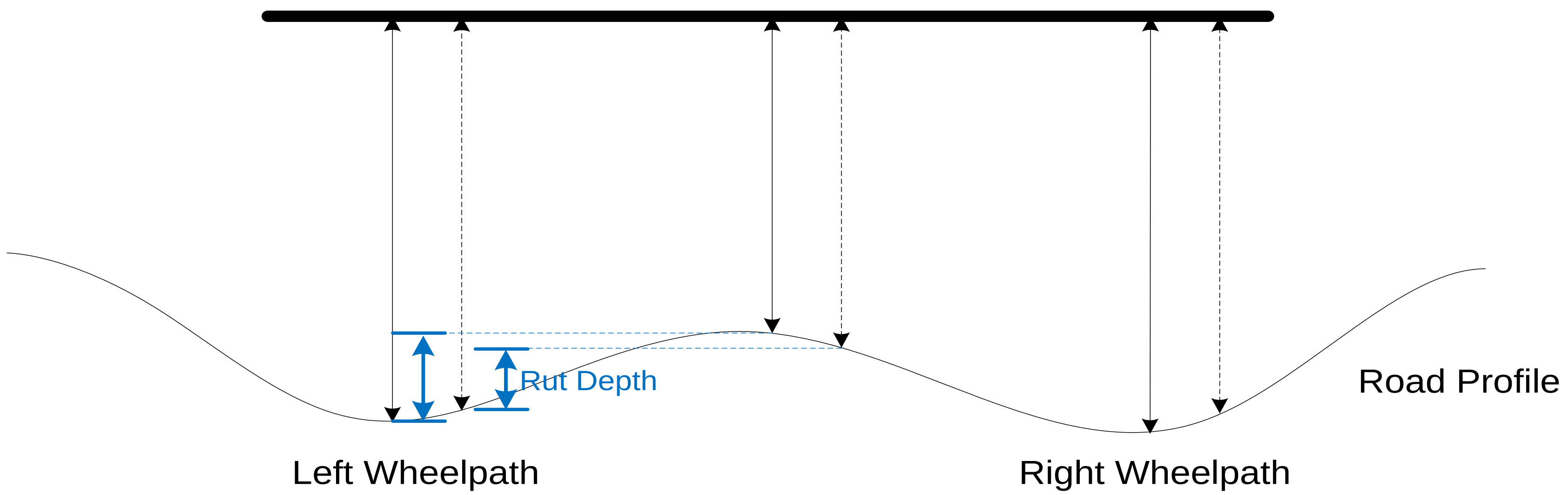




1. Rutting

- Rut depth measurement
- Localized rutting

Point-based Rut Bar



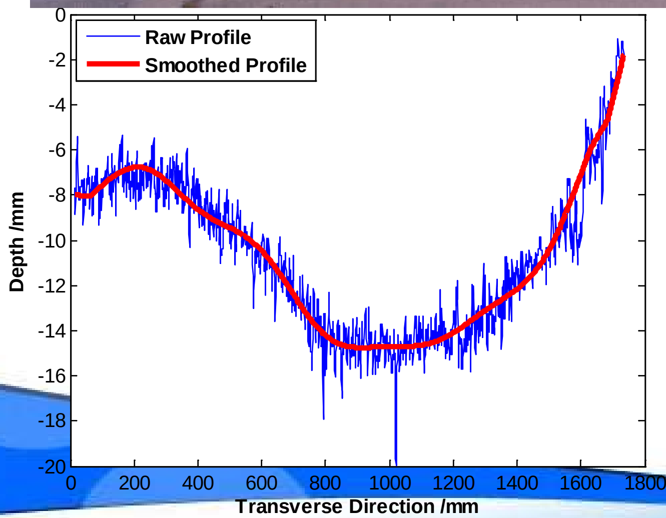
Automated Survey System	3-point	5-point	7-point to 37 point
Number of Highway Agencies	16	13	11

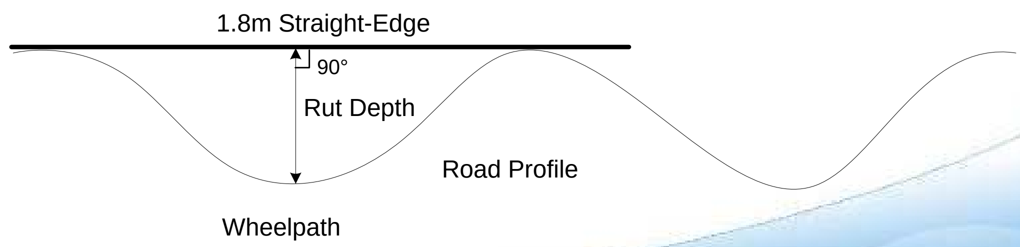
(McGhee 2004)

Rut Depth Measurement

1. Lab Test

2. Field Test





Accuracy of Rut Depth Measurement (1)

Note: **1. Lab Test** (Absolute error less than 1mm)

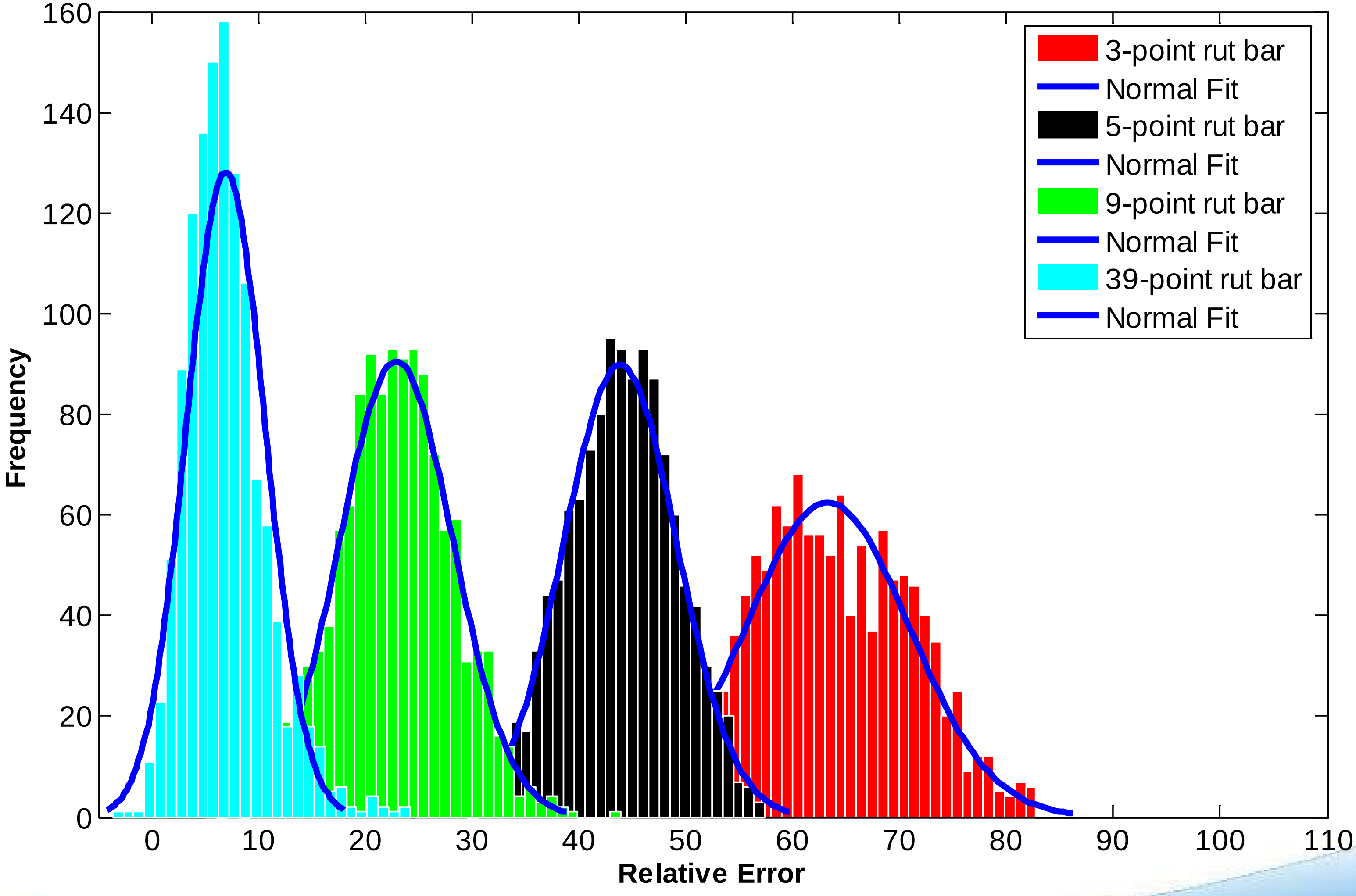
Profile #	Severity Level	Rut Depth (mm)					
		Ground Truth	LCMS Measured				Difference to Ground Truth
			1st Run	2nd Run	Difference between Runs	Average	
1	low	8.04	8.26	7.12	1.14	7.69	**0.35**
2	low	7.92	8.16	7.99	0.17	8.08	**-0.16**
3	low	7.94	6.79	7.57	0.78	7.18	**0.76**
4	medium	13.22	13.22	13.05	0.17	13.14	**0.08**
5	low	12.34	12.27	11.47	0.8	11.87	**0.47**
6	medium	14.24	13.75	14.03	0.28	13.89	**0.35**
7	medium	15.54	15	14.8	0.2	14.9	**0.64**
8	medium	16.24	15.41	16.7	1.29	16.06	**0.18**
9	medium	17.46	17.57	17.13	0.44	17.35	**0.11**
10	medium	10.04	10.97	9.68	1.29	10.33	**-0.29**
11	high	43.38	43.24	--	--	43.24	**0.14**

Accuracy of Rut Depth Measurement (2)

Note: **2. Field Test** (Absolute error about 2mm)

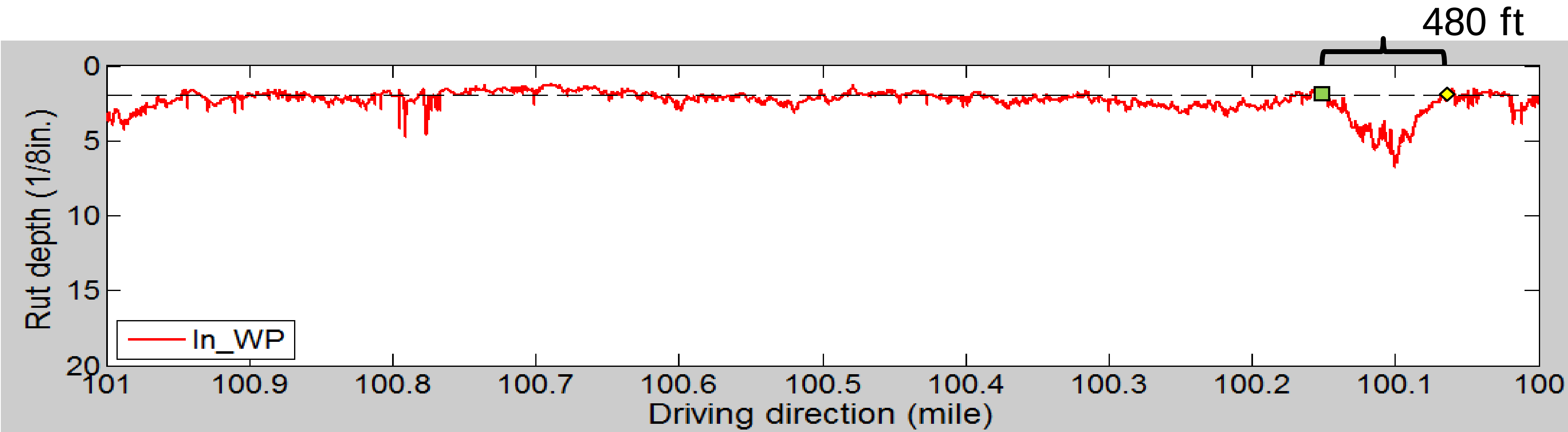
Profile #	Severity Level	Rut Depth (mm)					
			LCMS Measured				Difference to Ground Truth (mm)
		Ground Truth	1st run	2nd run	3rd run	Average	
1	Medium	14.5	12.1	14.0	13.5	13.2	**1.3**
2	Medium	15.8	13.4	14.6	12.8	13.6	**2.2**
3	Low	9.6	10.7	10.8	10.3	10.6	**-1.0**
4	Medium	14.2	12.9	12.1	11.3	12.1	**2.1**
5	Low	8.5	6.0	6.7	7.6	6.8	**1.7**
6	Low	9.5	7.3	7.2	7.1	7.2	**2.3**
7	Low	7.8	5.9	6.0	6.6	6.2	**1.6**
8	Low	9.4	7.2	7.1	7.2	7.2	**2.2**
9	Medium	21.1	19.8	20.8	20.3	20.3	**0.8**
10	Low	6.4	5.7	4.7	5.3	5.2	**1.2**

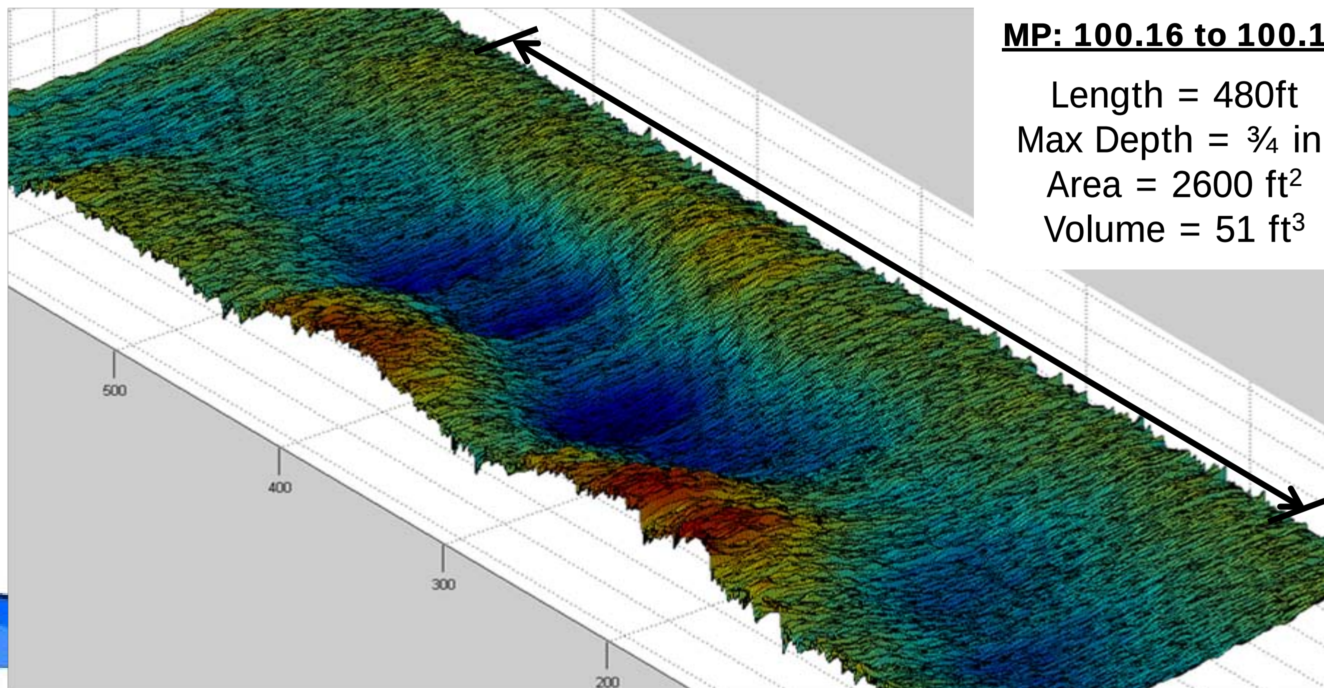
Assessment of Rut Bar System Errors



Isolated Rut on I-95

Isolated Rut Identification and Measurement



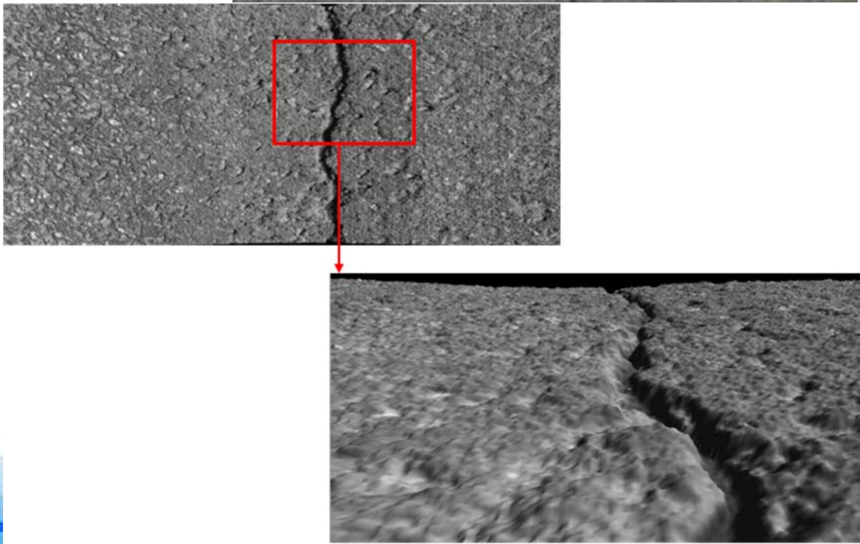


MP: 100.16 to 100.17

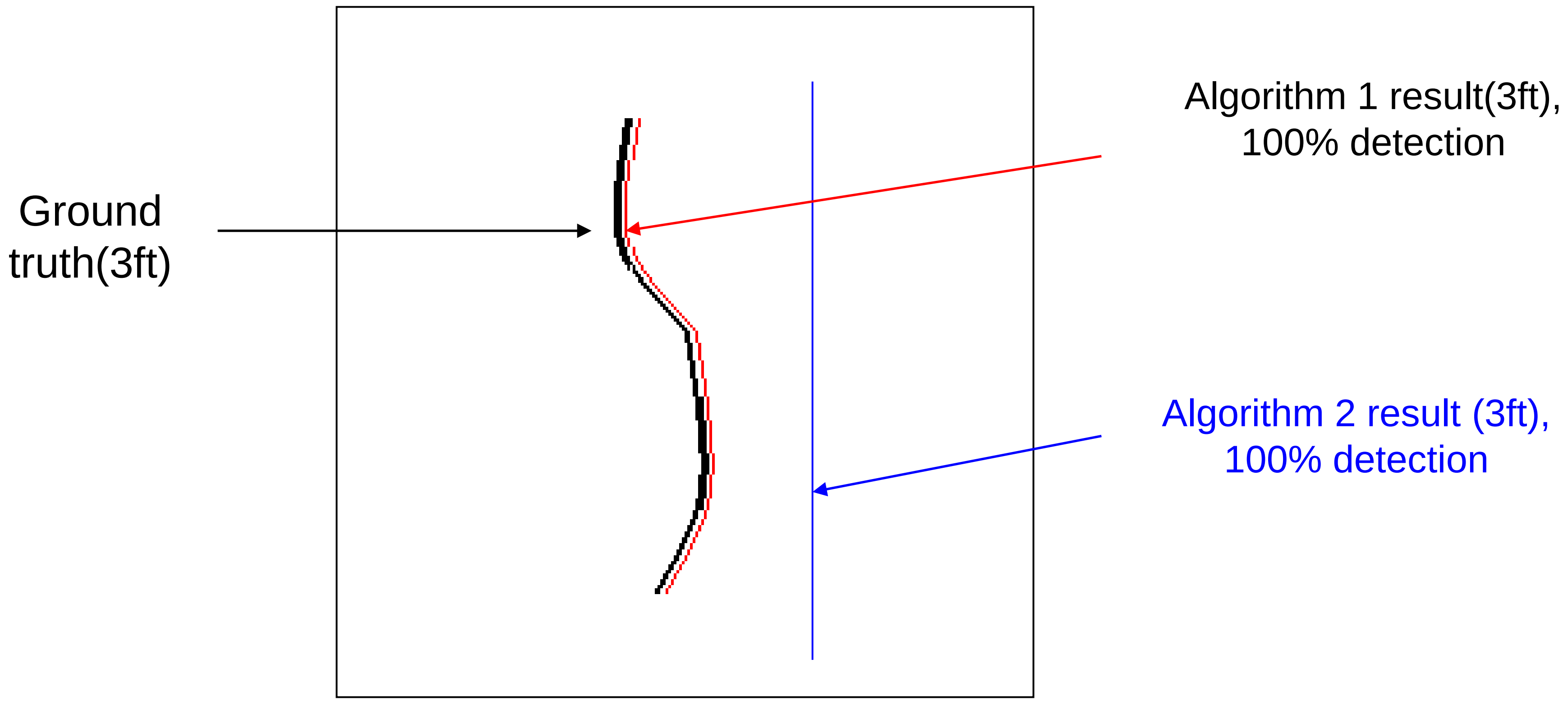
Length = 480ft
Max Depth = ¾ in.
Area = 2600 ft^2
Volume = 51 ft^3

Cracking

- Automatic crack detection
- Performance evaluation

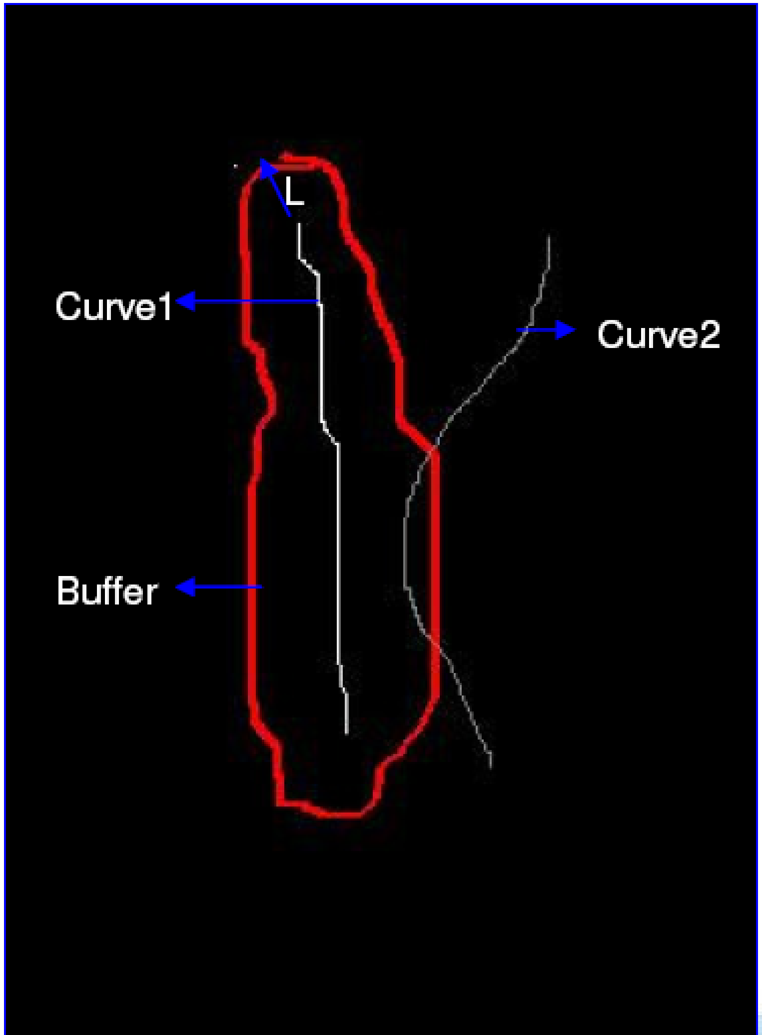


Problem on Region-based Performance Measurement



5ft by 5ft pavement area sample

Linear Buffered Hausdorff Quantification Method

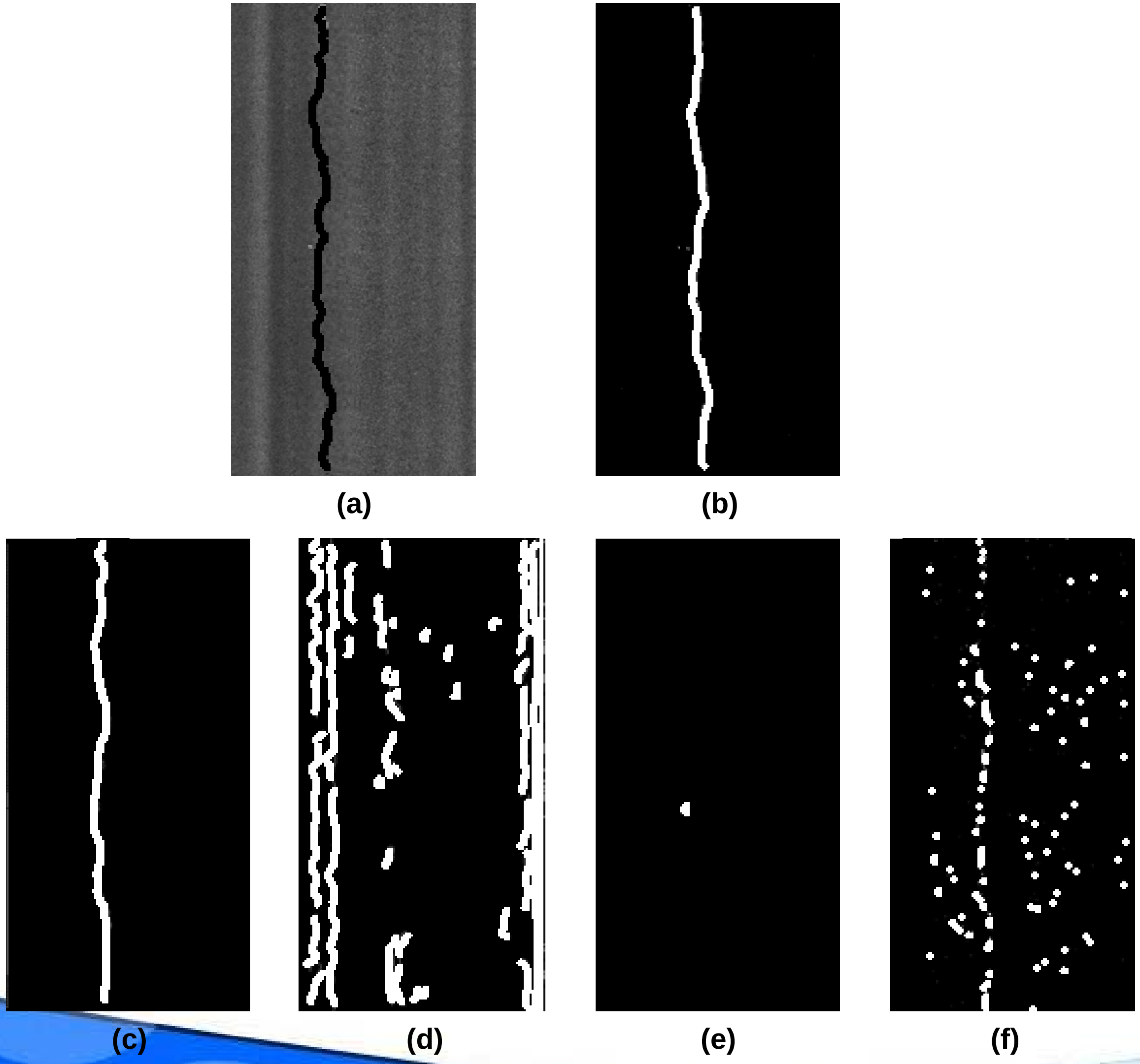


$$BH(A,B) = \max(h(A,B), h(B,A))$$

$$h(A,B) = \frac{1}{m}\sum_{a \in A} \underset{L}{sat} \min_{b \in B} \|a-b\|$$

$$\text{Scoring Measure(SM)} = 100 - \frac{BH(A,B)}{\text{L}}$$

A Buffered Hausdorff Distance Scoring Method



(a) Original Image

(b) Ground Truth Image

(c) Dynamic Optimization Result
Score: 92

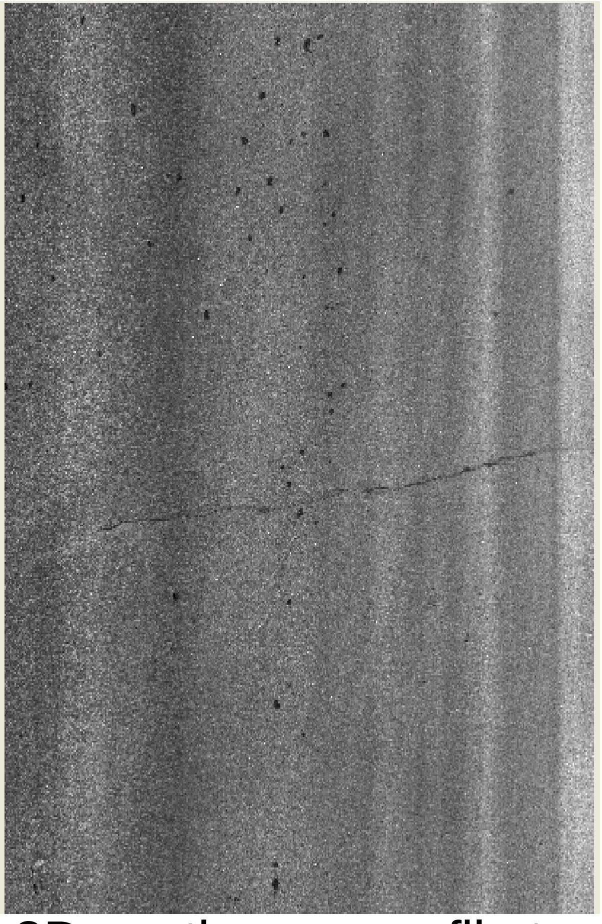
(d) Canny Edge Detection Result
Score: 14

(e) Crack Seed Verification Result
Score: 3

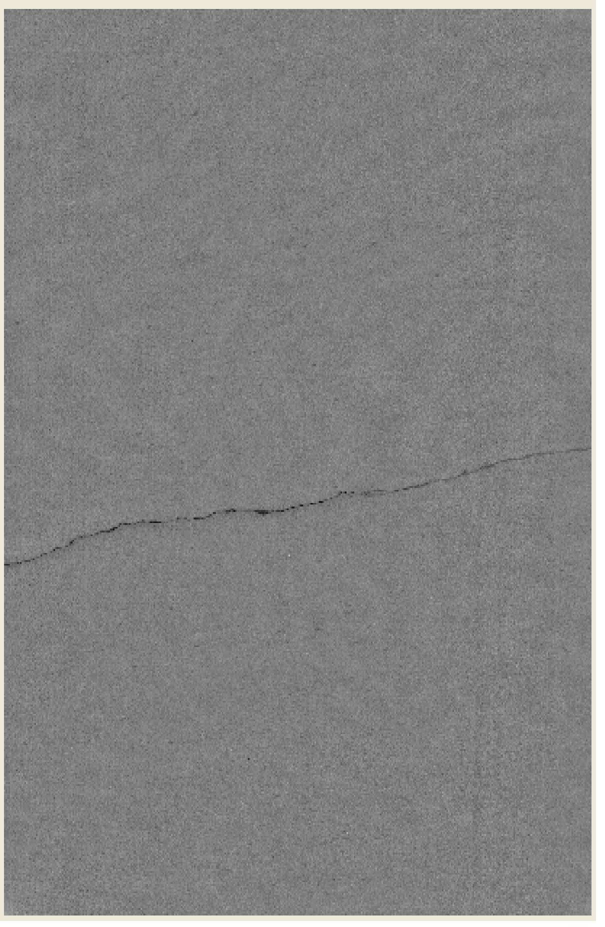
(f) Iterated Clipping Result Score: 64

Advantage of 3D data over 2D data on crack detection

2D data

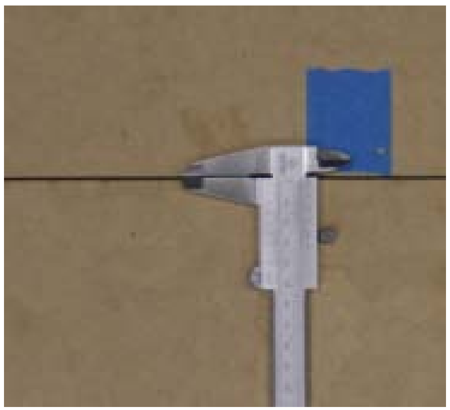


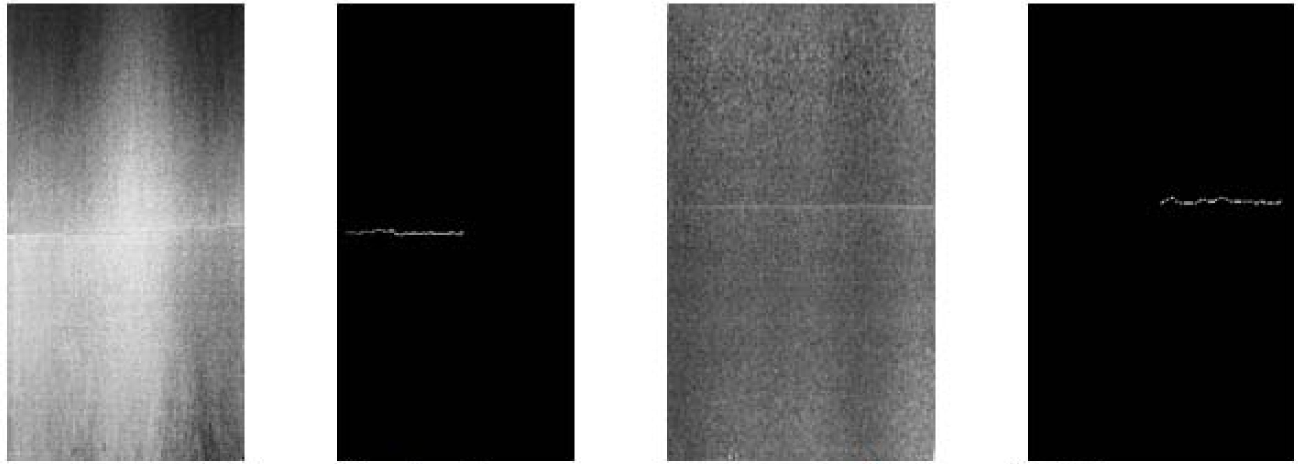
3D data



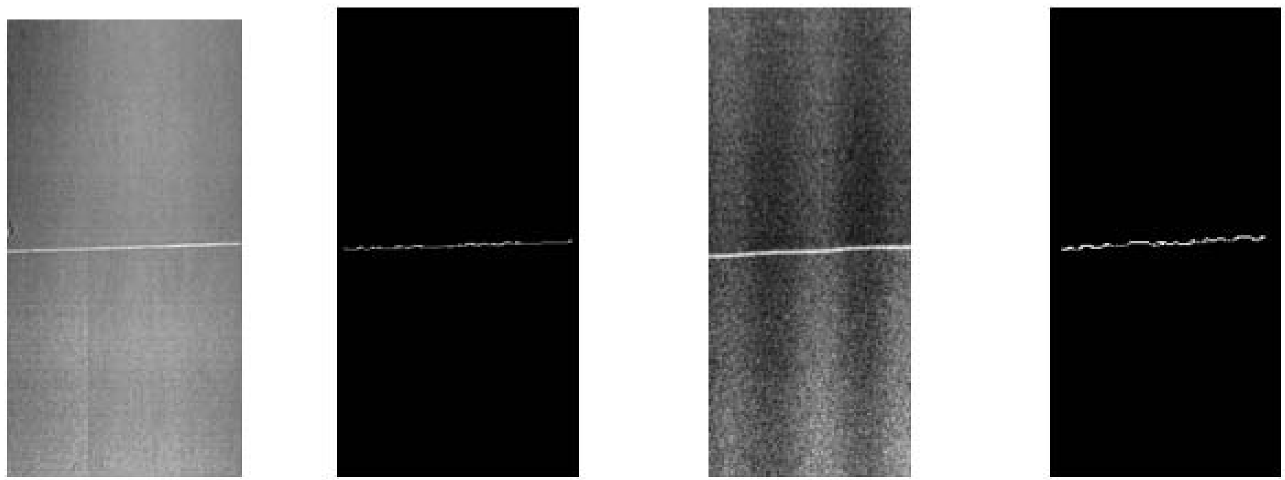
With 3D continuous profile technology, it is a lot more clear to distinguish a crack from the surrounding pavements

Laboratory Test for Crack Detection



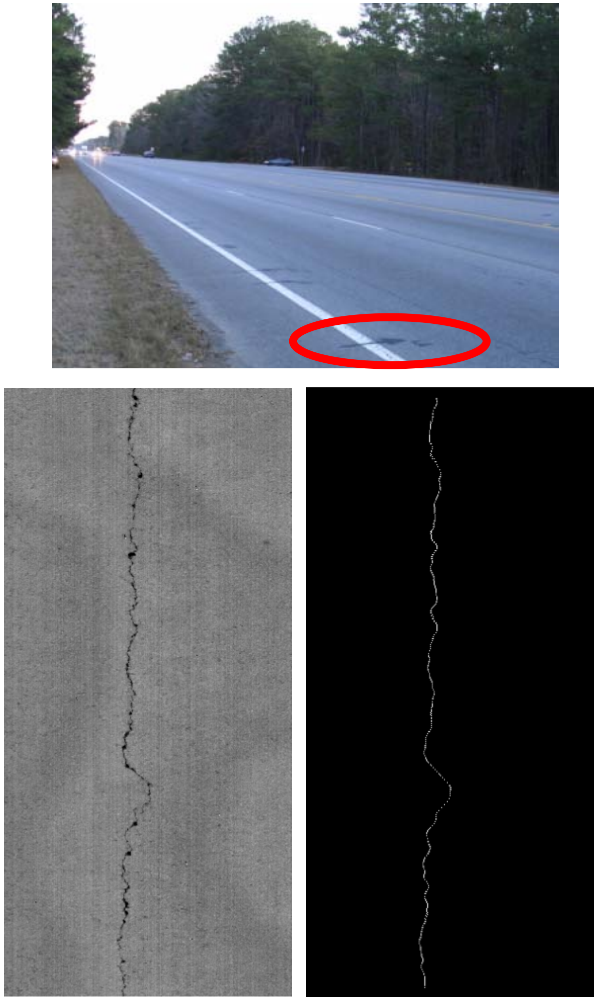


(a) 1mm (daytime) (b) 1mm (night)

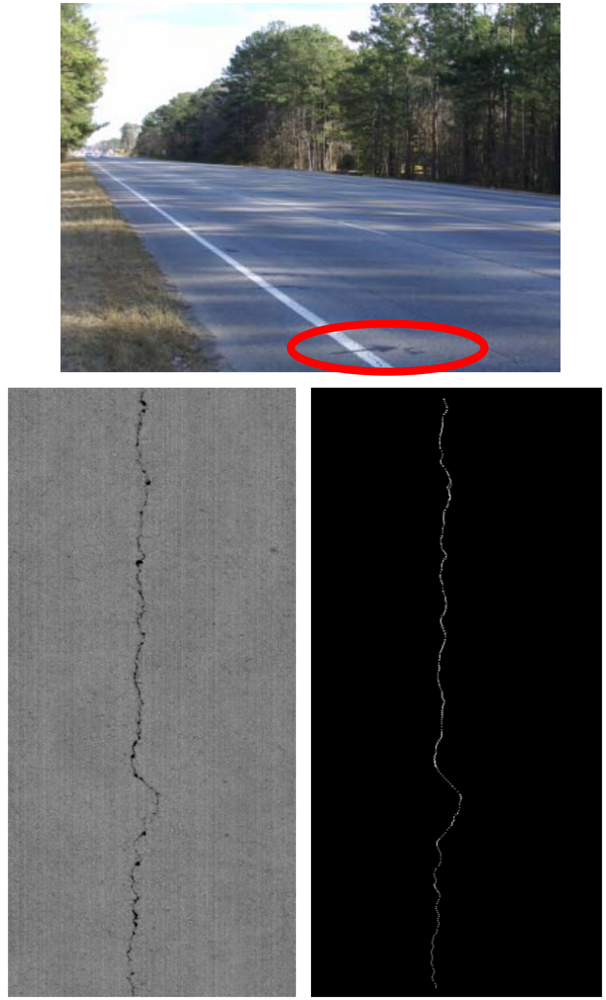


(c) 2mm (daytime) (d) 2mm (night)

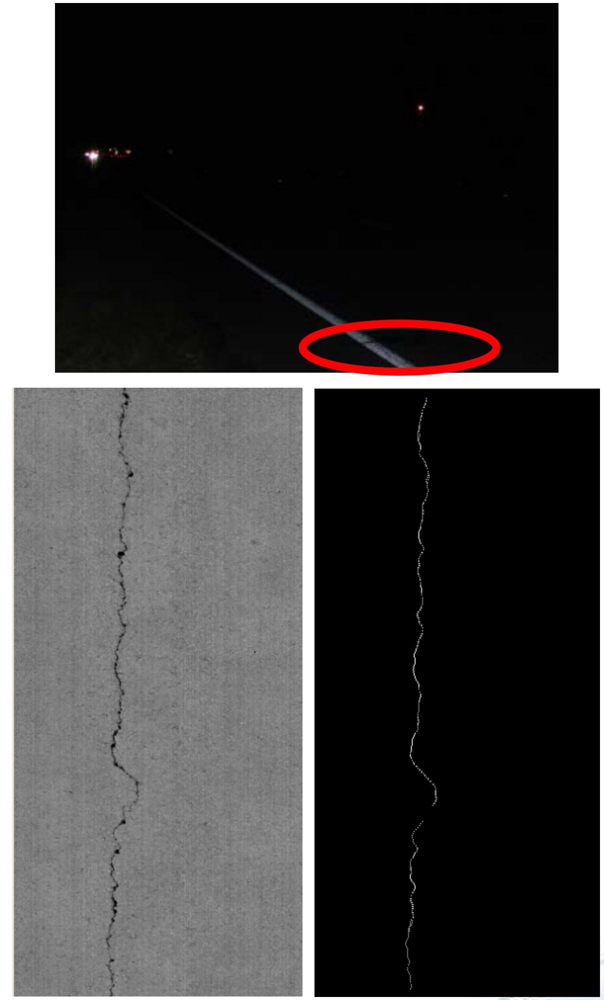
Field Test for Crack Detection (1)



Daytime (no shadow)

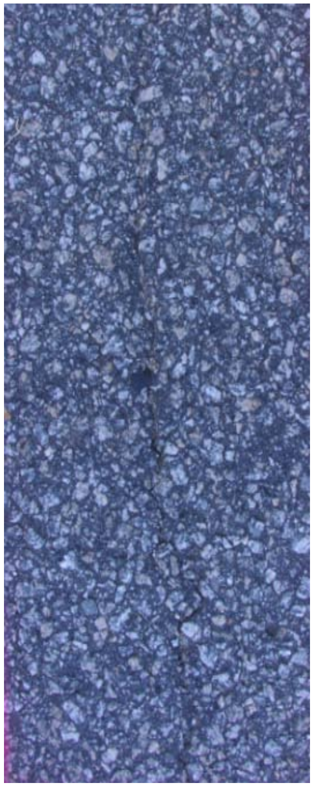


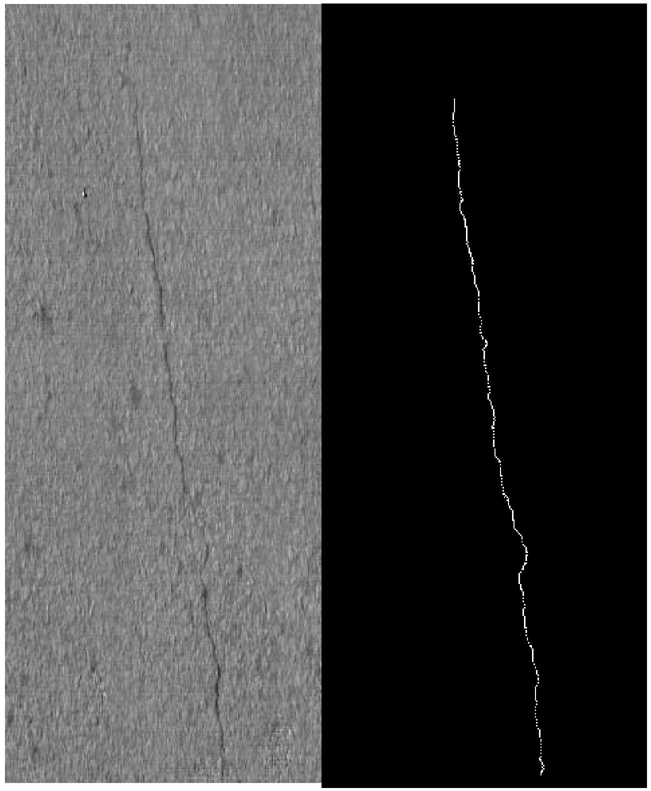
Shadow



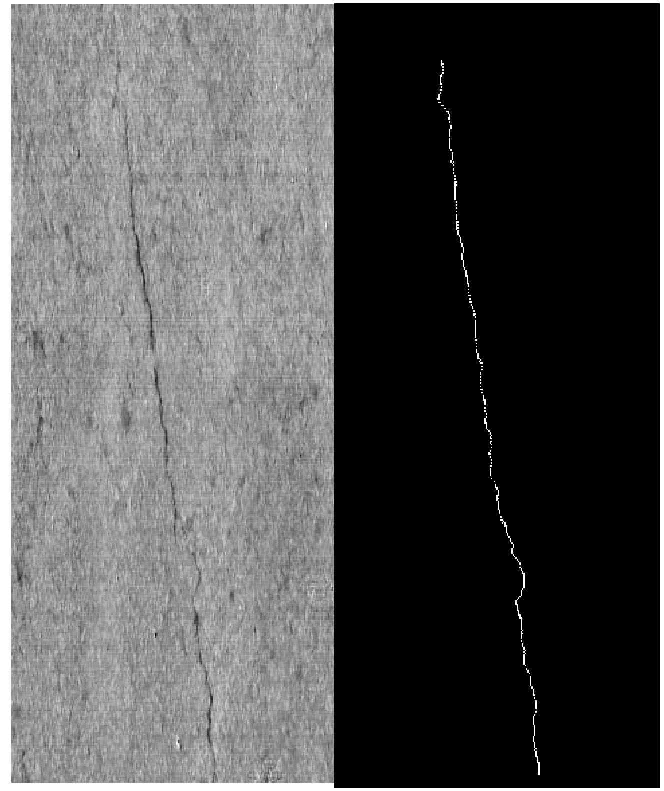
Night

Field Test for Crack Detection (2)



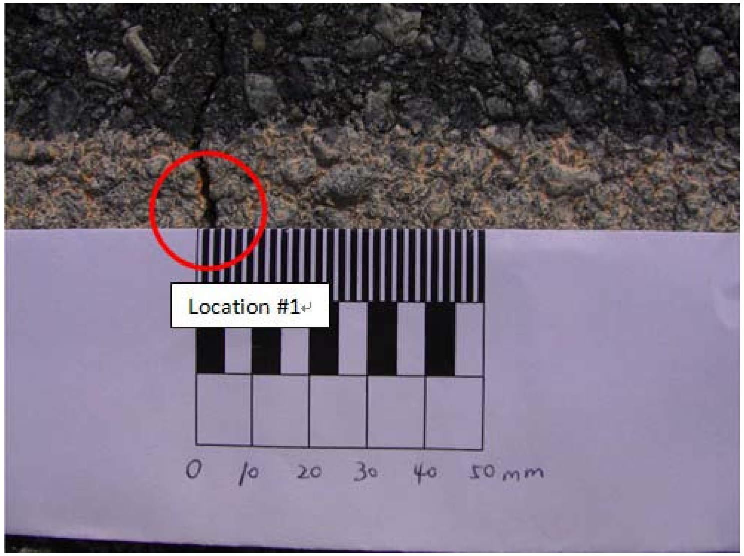


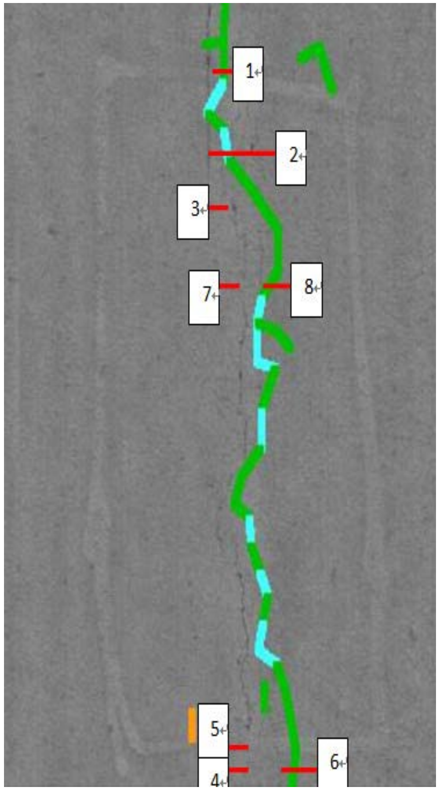
Daytime (score = 98.3)

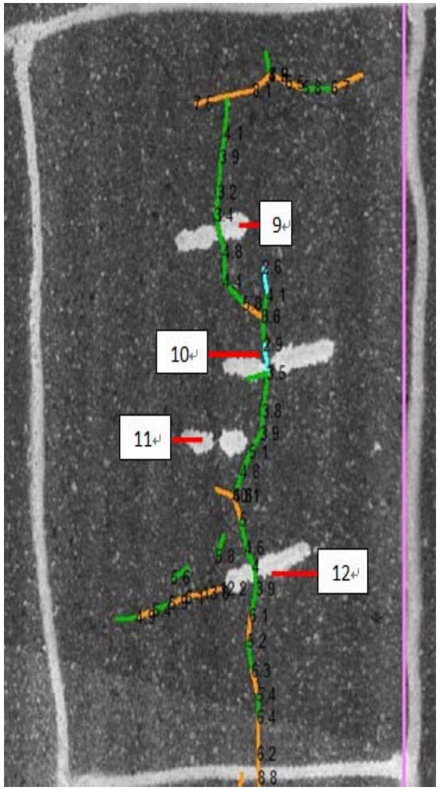


Night (score = 98.0)

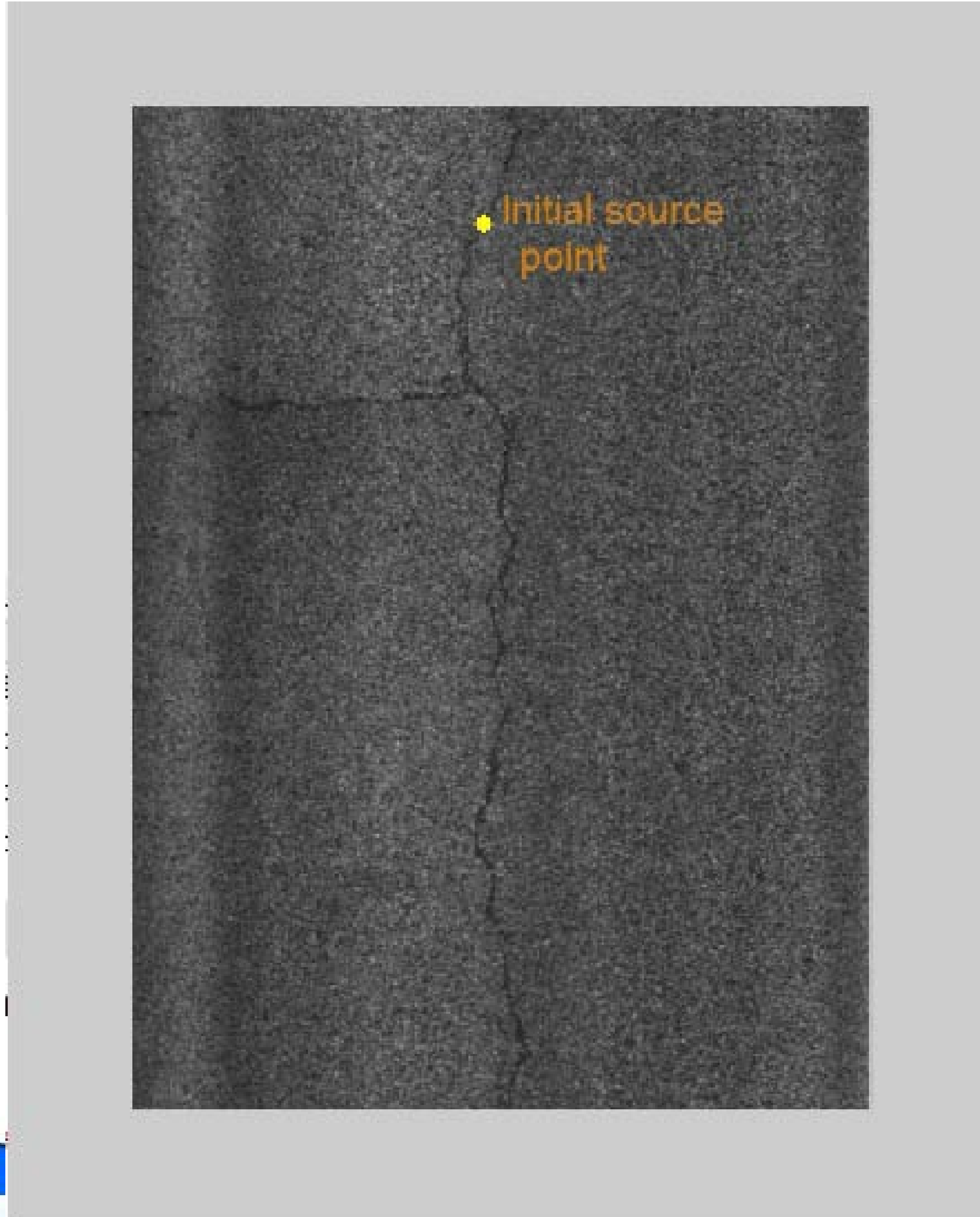
Crack Width Measurement (1)







Demo Video



Validation of Pavement Condition Assessment Using 3D Line Laser Imaging Technology (on-going tasks)

- Asphalt pavement crack classification
- Concrete pavement condition evaluation (faulting, spalling, crack, should joint drop, etc.)

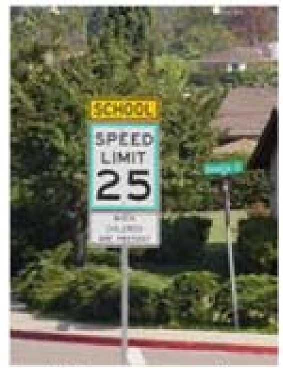
3. Traffic Sign Inventory

- Using mobile LiDAR and image processing algorithms
- Sign retro-reflectivity condition assessment

Image-based Traffic Sign Detection

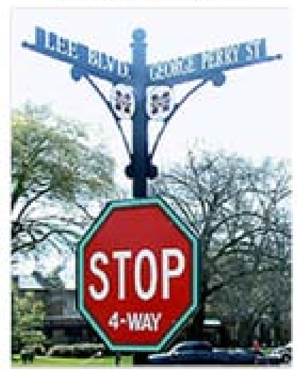
- MUTCD Shapes: circle, triangle, rectangle, pentagon, Octagon, etc.

(a) Triangle



(b) Rectangle

(c) Pentagon

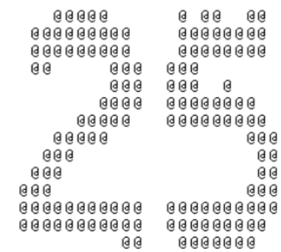


(d) Octagon

Sign Recognition Using Image Pattern Recognition Algorithms

(a) Raw image containing speed limit sign

(b) Processed binary image after color segmentation



(c) Extracted speed limit digits

Incorporated other features, Harr features derived from the **Adaboost Cascade algorithm**, used effectively in **face recognition**

Sign Pattern Recognition

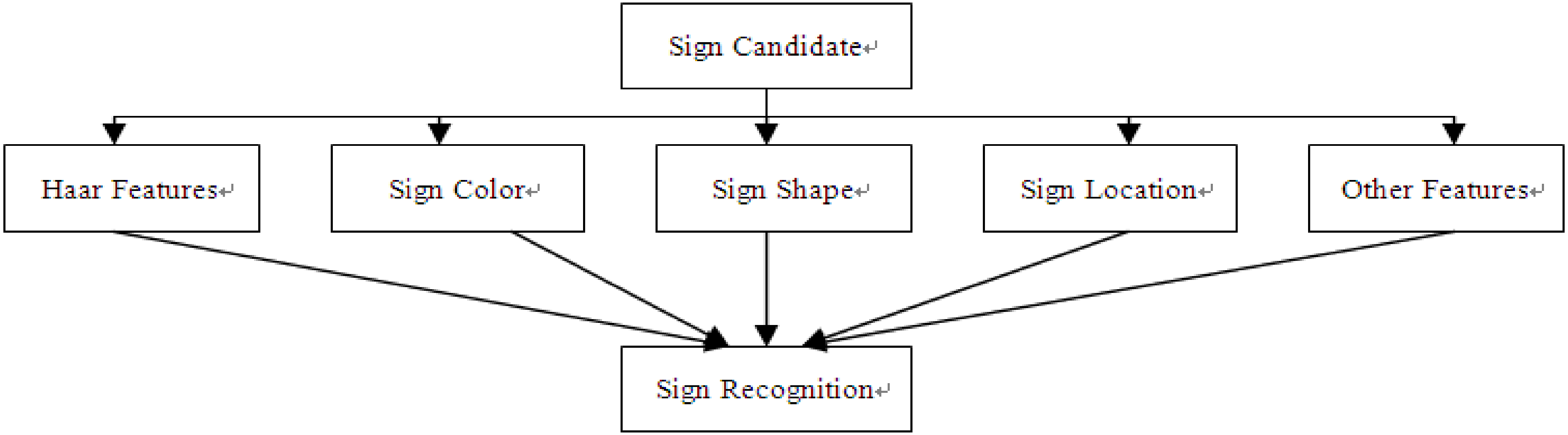


FIGURE 9 Sign recognition from multi-features.

(NCHRP IDEA Final Project Report, Tsai, 2009)

Sign Detection Demo

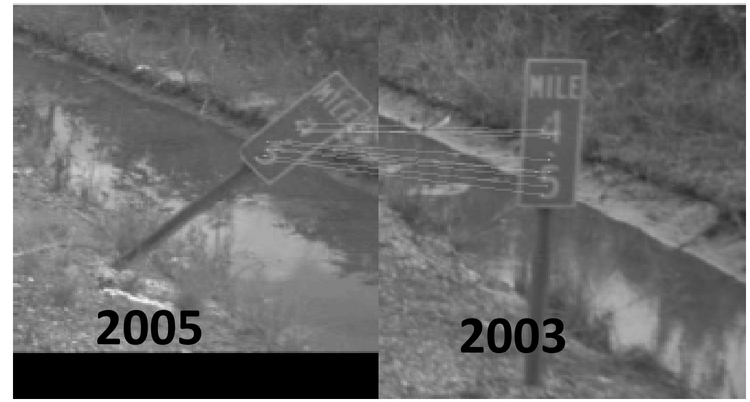
Sign Condition Change Detection

Sign Change Detection

(a)

(b)

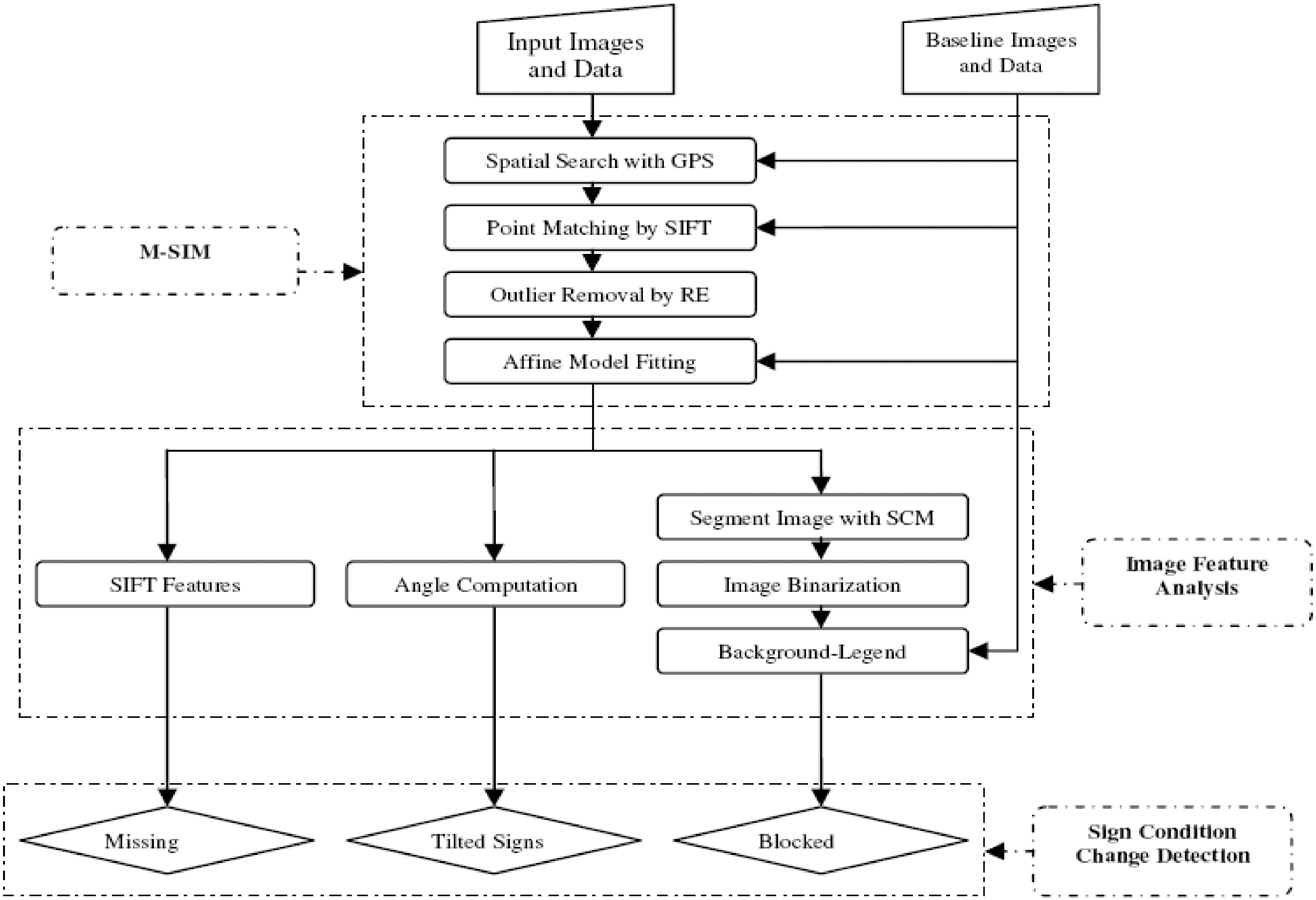
Figure 11. Spatial searching with GPS coordinates: a) A tilted milepost sign taken in FY 2005; b) Two baseline candidate images taken in FY 2003 are selected through GIS spatial search.



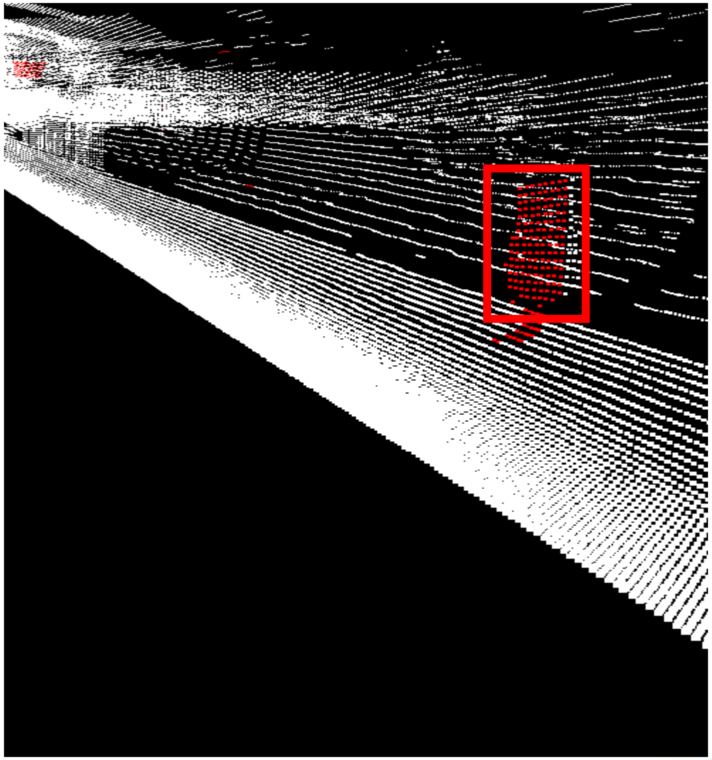
Scale-invariant Feature Transform (SIFT)

Courtesy of LADOTD for providing testing images.

Sign Change Detection (cont.)



Use of Mobile LiDAR for Sign Detection



Summary

- It is promising to use emerging sensor technology to develop a cost-effective measurement technology.
- 3D line laser imaging technology is capable of building a “All Purpose” device for assessing pavement surface conditions: rutting, cracking, potholes, macro-texture, etc.
- The accuracy and repeatibility of rut depth measurement can be improved using 3D line laser technology. It can be applied for network-level rutting survey and isolated rut identification.
- The accuracy of crack detection and width measurement can be improved using 3D line laser imaging technology.
- It can be further applied to crack classification and concrete condition assessment (e.g. faulting, spalling, broken slabs).
- Mobile LiDAR and image processing algorithms can be used to improve the efficiency of sign data collection under a well-designed sign inventory procedure.

Outreach Plan

- Work with GDOT to initiate pilot studies to extend the research results to practical application: I-285 interstate highway pavement condition evaluation to demonstrate the practical use of the technology and how to generate the information, including report that can support pavement maintenance operation and decision-making.

Thanks