Technology Overview on Validating 3D Transverse Profile Data and Measurement of Pavement Surface Distresses

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- Other Team Members
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  - Yiching Wu, Research Engineer in School of Civil and Environmental Engineering
  - Former Students:
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  - Current Students:
    - Chenglong Jiang; Yipu Zhao; Sean Gann; Geoffrey Price; Yuanfang Wang; Laura Boyle

Outline

- Introduction to 3D line laser system
- Characteristics of 3D laser data
- 3D calibration
- Validation of range measurement accuracy using a validation board
- Validation of derived data accuracy
- Summary

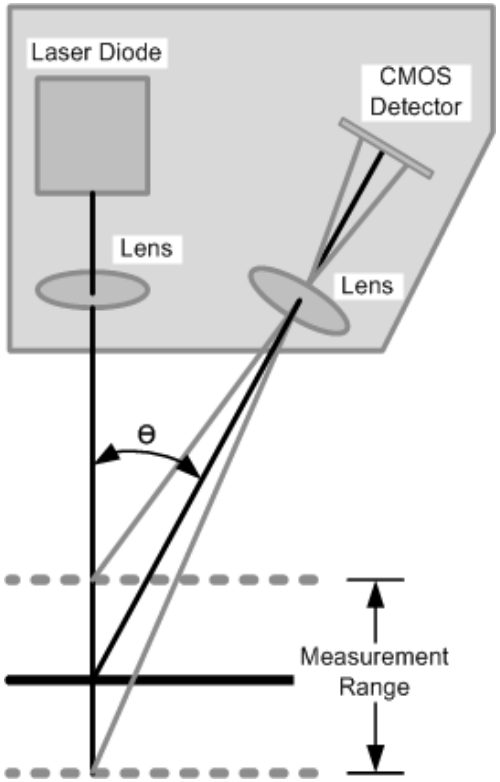
A Brief History of 3D Laser Scanning

- 3D laser scanning started from 1960s
- The first triangulation-based 3D laser scanning technology was developed in 1978
  - Other types of 3D laser scanning: time of flight and phase shift
- Advantage of laser stripe (line laser)
  - Faster than point laser and as accurate as point laser
- Commercialized systems for pavement engineering (started from 2010)
  - Pathway 3D Imaging
  - Pavemetrics LCMS
  - TxDOT 3D Transverse Profiling System
  - Waylink

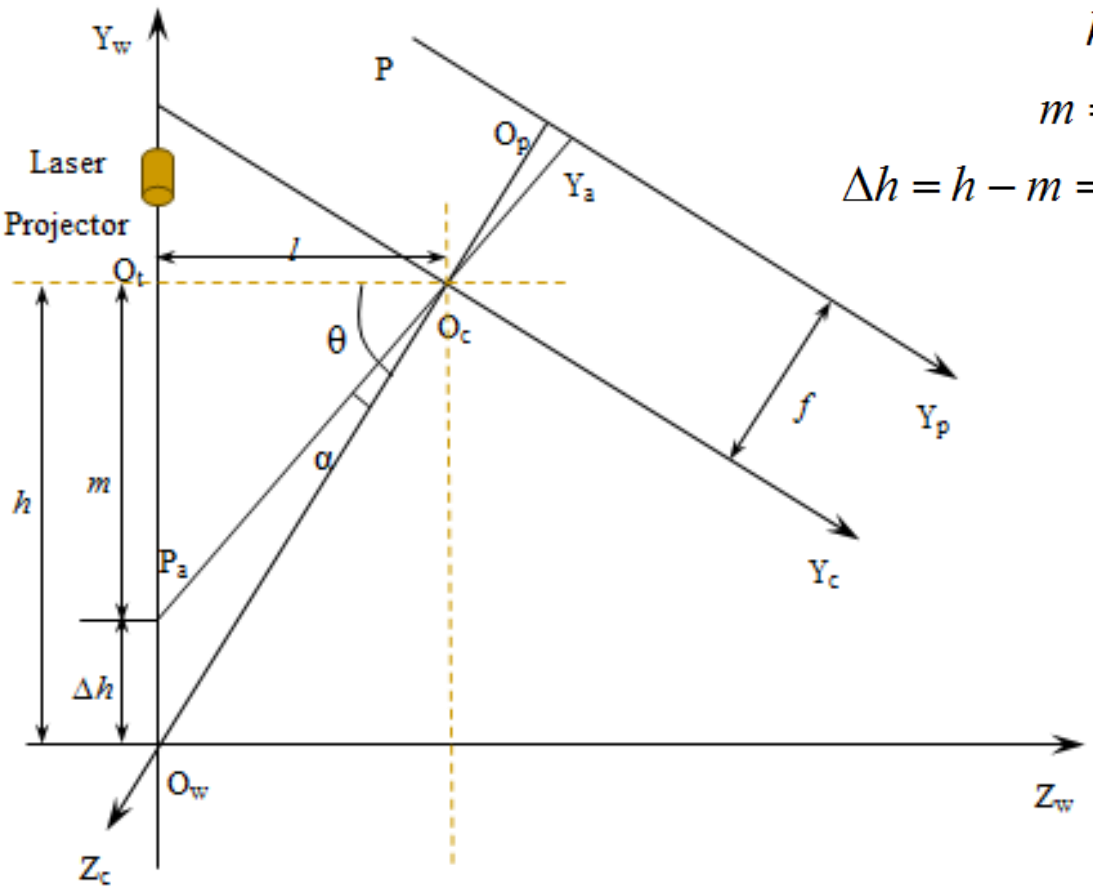
Ebrahim, M. A. (2011) "3D Laser Scanners: History, Applications, and Future" (http://www.researchgate.net).

Configuration of 3D Line Laser System

- Laser line projector
- Digital camera
- Distance measured by using laser triangulation
- **Need of a uniform terminology to name this technology in pavement engineering**
  - 3D line laser imaging
  - 3D laser imaging
  - 3D laser scanning
  - 3D transverse profiling



Laser Triangulation (2D Illustration)



$$\alpha = \arctan(y_a / f)$$

$$h = l \cdot \tan(\theta)$$

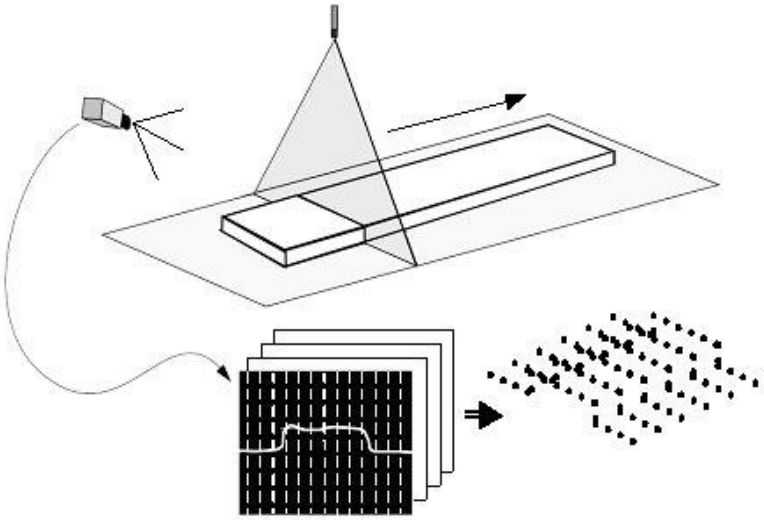
$$m = l \cdot \tan(\theta - \alpha)$$

$$\Delta h = h - m = l \cdot (\tan(\theta) - \tan(\theta - \alpha))$$

Li, Q., Yao, M., Yao, X., and Xu, B. (2010). “A Real-Time 3D Scanning System for Pavement Distortion Inspection.” Measurement Science and Technology, 21(2010), 015702.

Typical 3D Sensing System

Georgia Tech Sensing Vehicle

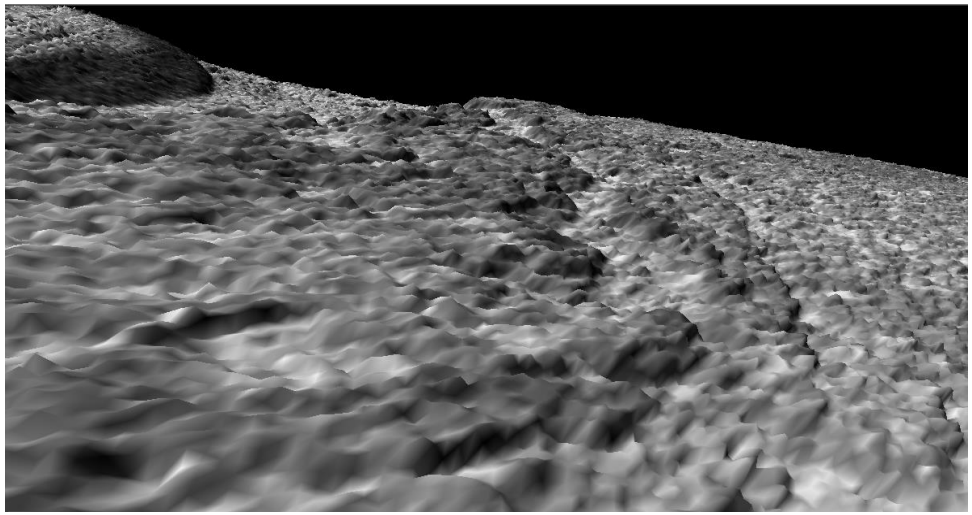


(Laurent, et al., 2008)

Laurent, J., Lefebvre, D., & Samson, E. (2008). “Development of a New 3D Transverse Profiling System for the Automatic Measurement of Road Cracks.” In Proceedings of the 6th Symposium on Pavement Surface Caracteristics, Portoroz, Slovenia.

Detailed Level of Measurements

- High resolution and performance 3D laser data.

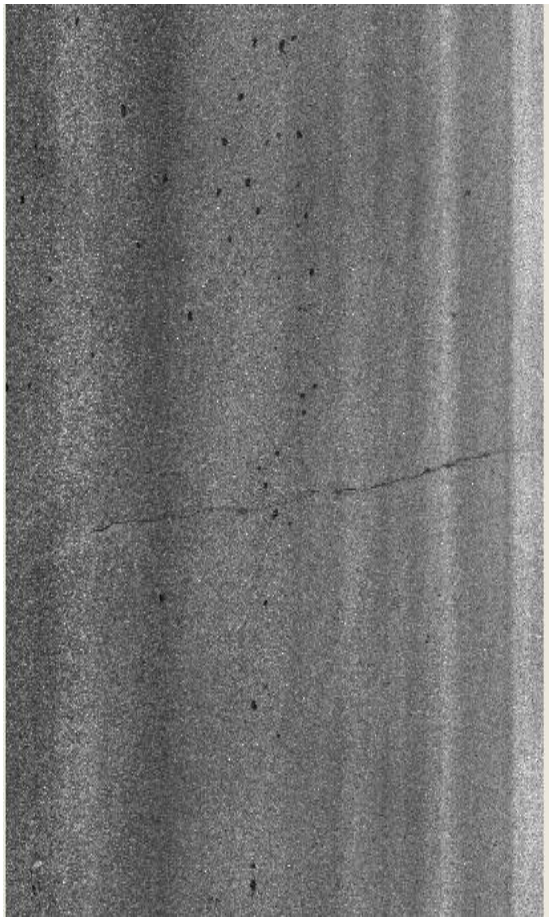


- Resolution
  - Driving dir.: 1 - 5 mm
  - Transverse dir.: 1 mm
  - Elevation: 0.5 mm
  - Data points collected per second and width covered
    - 2 (lasers) * 2048 (points/profile/laser) * 5600 HZ = 22,937,600 points/second

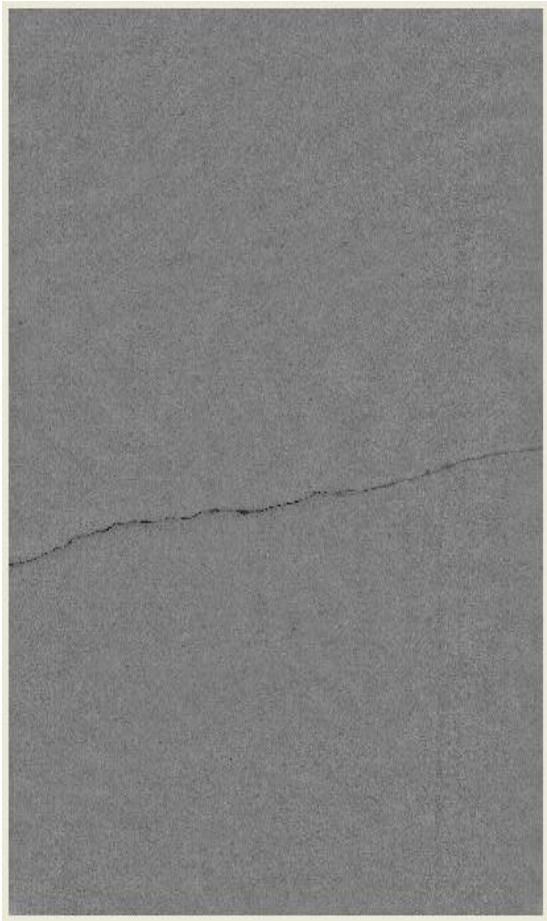
Note: The specification shown above is for the system tested by the PIs.

Advantage of 3D Data over 2D Data

2D data



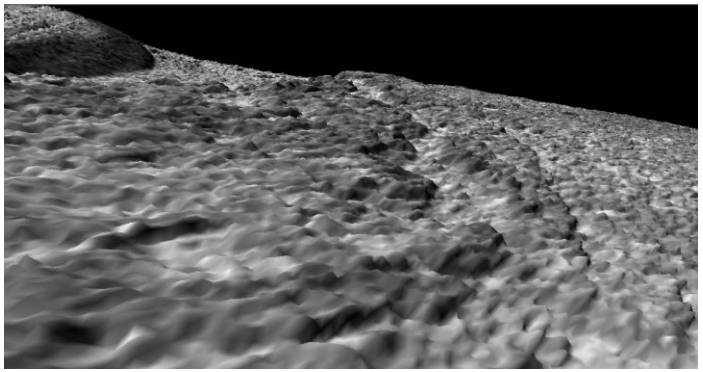
3D data



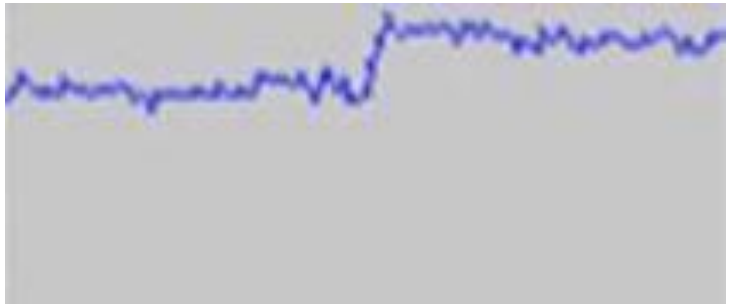
With 3D technology, it is much clearer to distinguish a crack from the surrounding pavements

Tsai, Y., Li, F. (2012) "Detecting Asphalt Pavement Cracks under Different Lighting and Low Intensity Contrast Conditions Using Emerging 3D Laser Technology", ASCE Journal of Transportation Engineering, 138(5), 649–656.

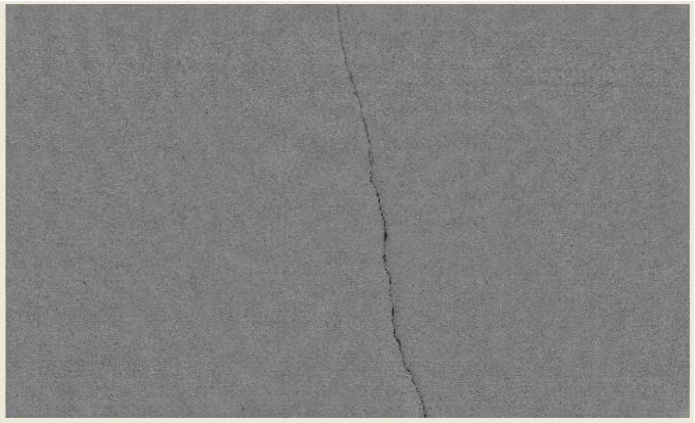
3D Laser Data and Its Applications



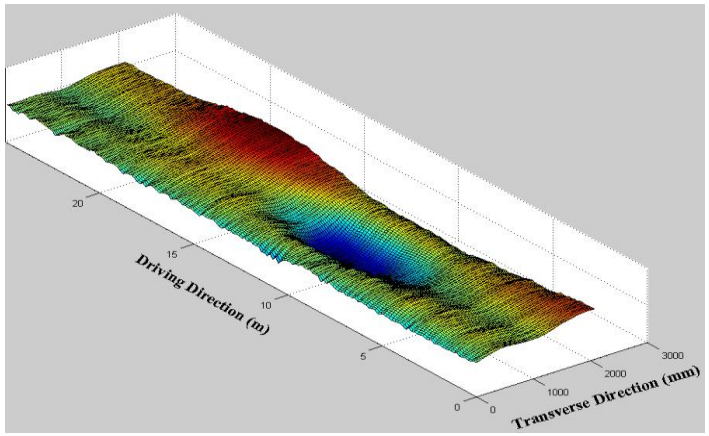
a. Texture



c. Joint/crack faulting



b. Crack



d. Rutting

Tsai, Y., Wu, Y., Ai, C., Pitts, E. (2012) "Feasibility Study of Measuring Concrete Joint Faulting Using 3D Continuous Pavement Profile Data," ASCE Journal of Transportation Engineering,138(11),1291-1296.
Tsai, Y., Li, F., Wu, Y. "Rutting Condition Assessment Using Emerging 3D Line-Laser Imaging and GPS/GIS Technologies", the International Conference on Road and Airfield Pavement Technology, Taipei, Taiwan, July 14, 2013.

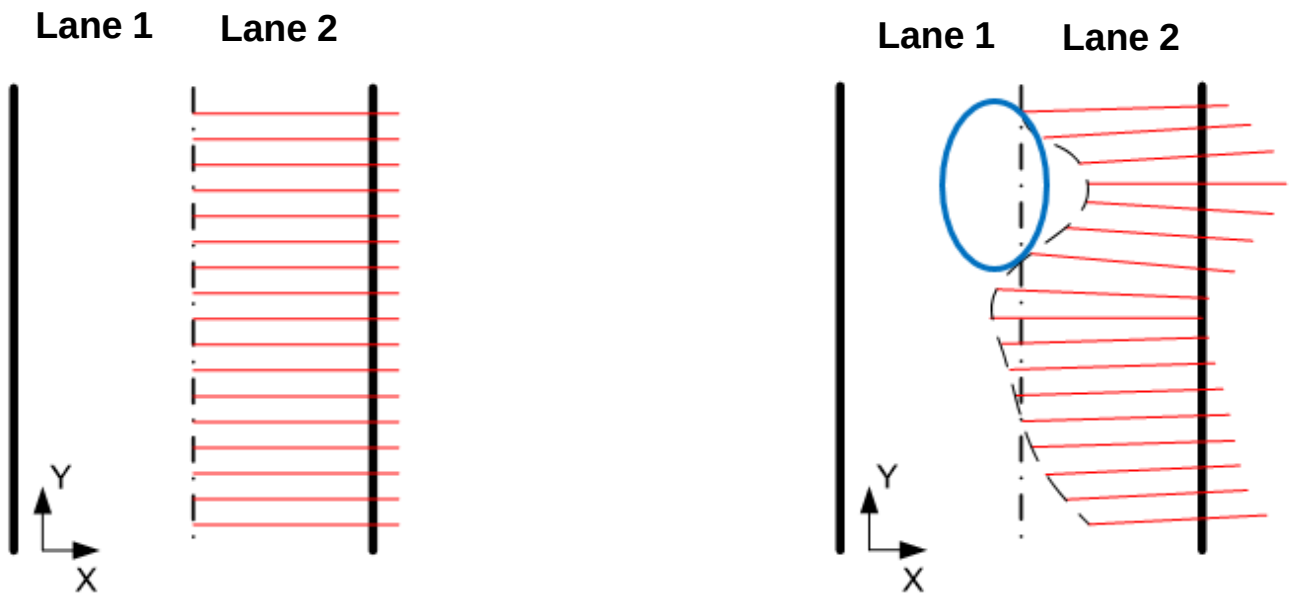
Characteristics of 3D Range Data (1)

- Data Uncertainty/Noise
  - Speckle noise (in static mode)
  - Change of surface brightness and/or color (will affect laser line detection due to the use of algorithms, e.g. center of gravity, for determining laser stripe peak position)
  - Missing range data
    - Out of measurement range (e.g. ± 125 mm in Tsai's tested system)
    - Occlusion
    - Dim laser point (or bright background)
  - Unseemly data (abnormally high or low point)
    - Shiny or mirroring object surface

Li, F. (2012). "A Methodology for Characterizing Pavemen Rutting Condition Using Emerging 3D Line Laser Imaging Technology." Ph.D. dissertation, Georgia Institute of Technology.

Characteristics of 3D Range Data (2)

- Impact of Vehicle Movement



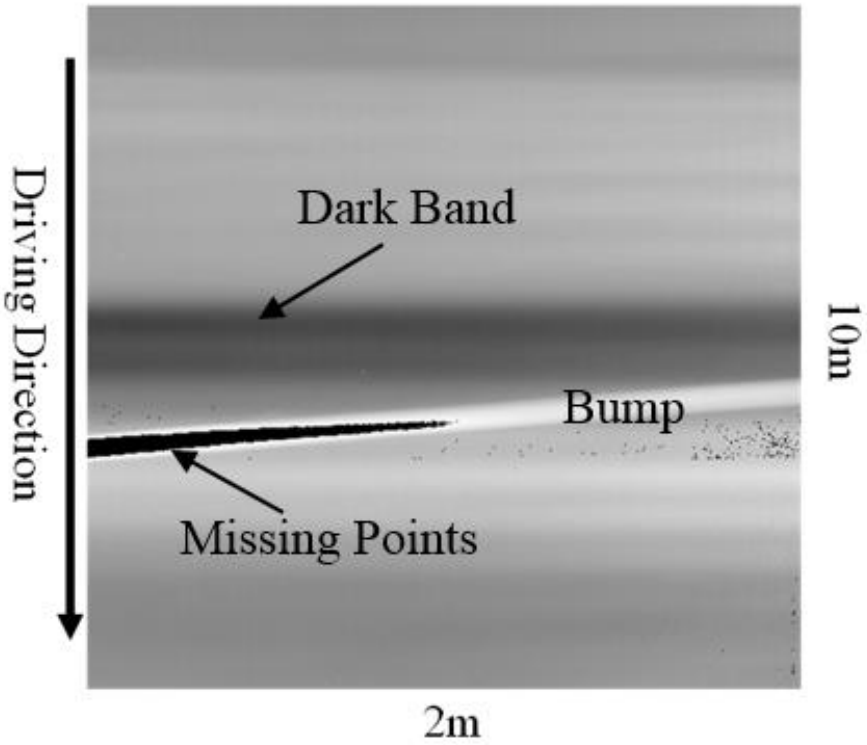
(a) Ideal case **(b) Data Collected when Vehicle Moves**

Location Uncertainty due to Vehicle Wanders and Rotates

Li, F. (2012). "A Methodology for Characterizing Pavemen Rutting Condition Using Emerging 3D Line Laser Imaging Technology." Ph.D. dissertation, Georgia Institute of Technology.

Characteristics of 3D Range Data (3)

- Impact of Bump

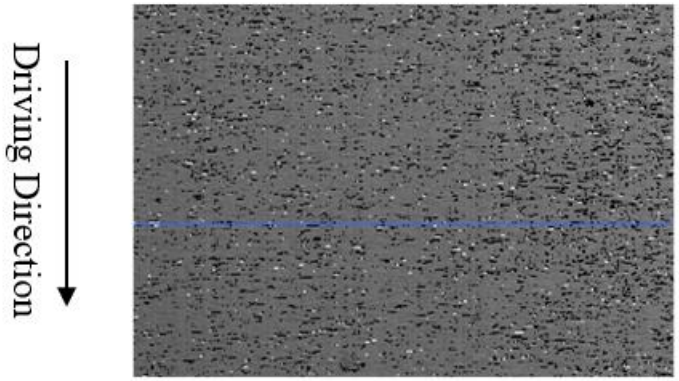


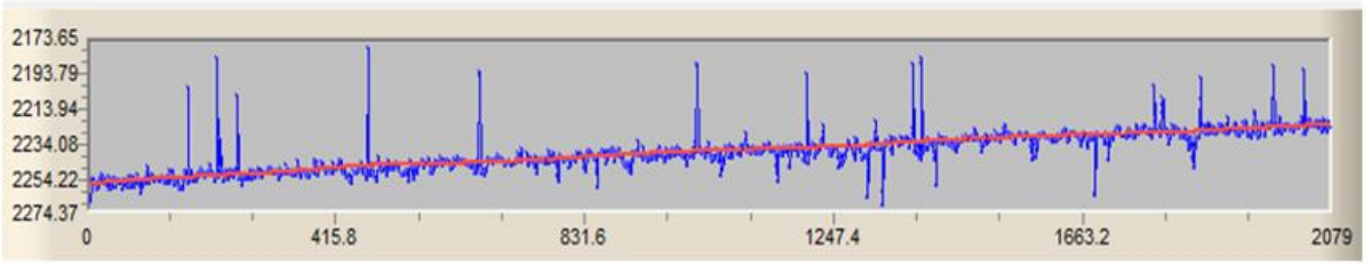
Data Collected When Passing a Bump

Li, F. (2012). "A Methodology for Characterizing Pavemen Rutting Condition Using Emerging 3D Line Laser Imaging Technology." Ph.D. dissertation, Georgia Institute of Technology.

Characteristics of 3D Range Data (4)

- Effect of New Pavement





Li, F. (2012). "A Methodology for Characterizing Pavemen Rutting Condition Using Emerging 3D Line Laser Imaging Technology." Ph.D. dissertation, Georgia Institute of Technology.

Calibration vs. Validation

- Calibration
  - "The set of operations that establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by material measure and the corresponding values of the measurand." (*National Conference of Standards Laboratories, NCSL RP-1, 1996*)
- Validation
  - Establishing documented evidence that provides a high degree of assurance that a specific process will consistently produce a product/measurement meeting its predetermined specifications and quality attributes (http://labmanual.net)

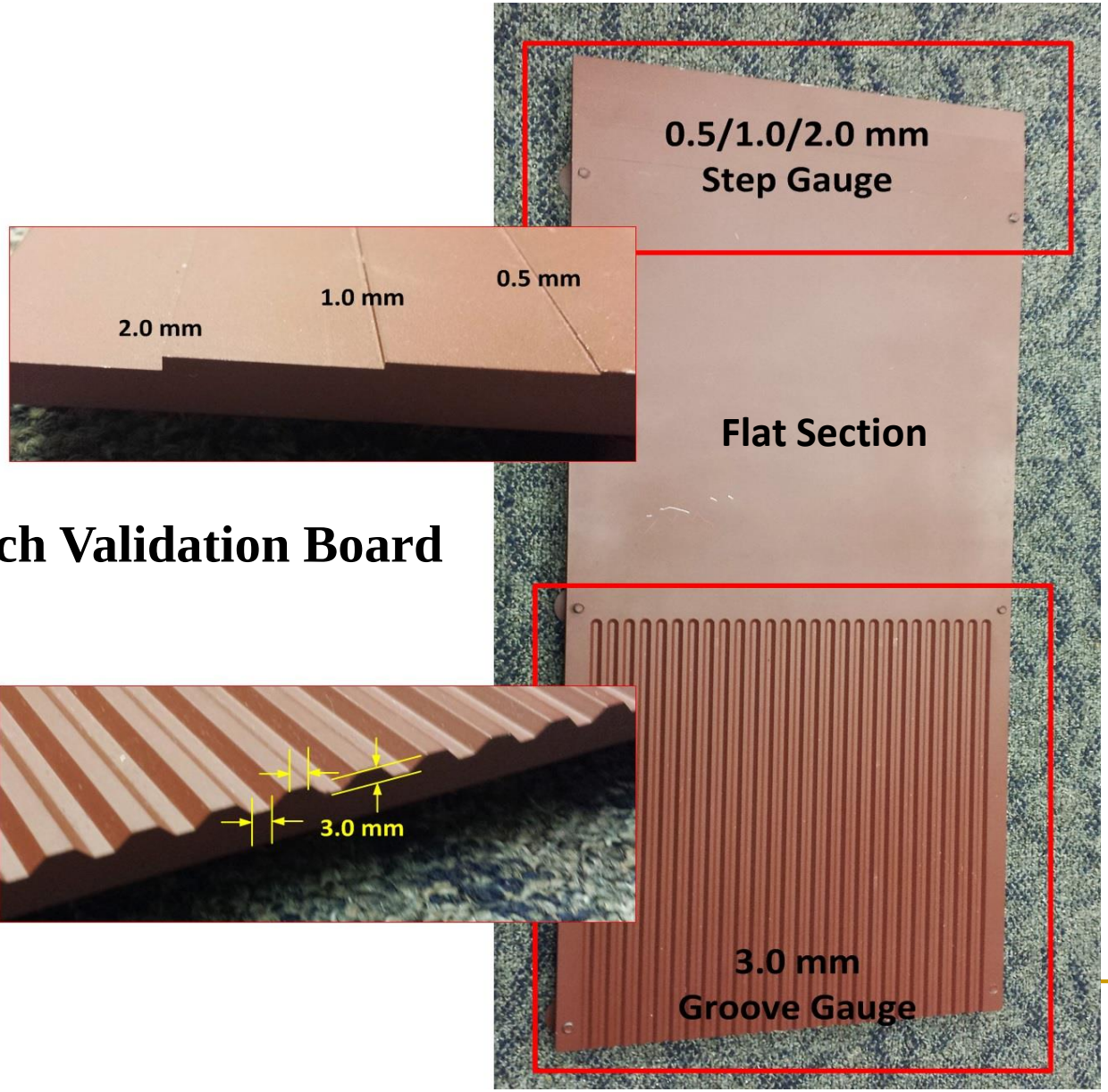
3D Calibration

- 3D calibration is to obtain real 3D measurements from a 2D image
  - Optical distortion (All lenses have some optical distortion which can sometimes be seen as making a straight line into a curved line in the image)
  - Range measurement (Parameters in laser triangulation, e.g. distance between laser line projector and camera, are obtained through calibration process with a known object)
- Calibration is performed by the device manufacturer. An end user can only perform validation for data quality assurance and quality control (QA/QC).

Validation: Objective and Approaches

- Validation of 3D laser data is to control data quality (accuracy and repeatability) and meet the requirements of data utilization (rutting measurement, crack detection and measurement, and texture analysis)
- Approaches of data validation
  - Validation of direct range measurement accuracy and/or repeatability using validation board
  - Validation of derived data accuracy and/or repeatability (rut depth, crack geometry, texture indicators, etc.)

Validation Board (Ga Tech) (1)



Georgia Tech Validation Board (GTVB)

Validation Board (Ga Tech) (2)

- Proposed validation procedure using GTVB. Both accuracy and repeatability will be evaluated.

Collect several runs of 3D laser data on VB (positioned under left sensor and right sensor, respectively)

↓

Use flat section to record/evaluate data noise/uncertainty

↓

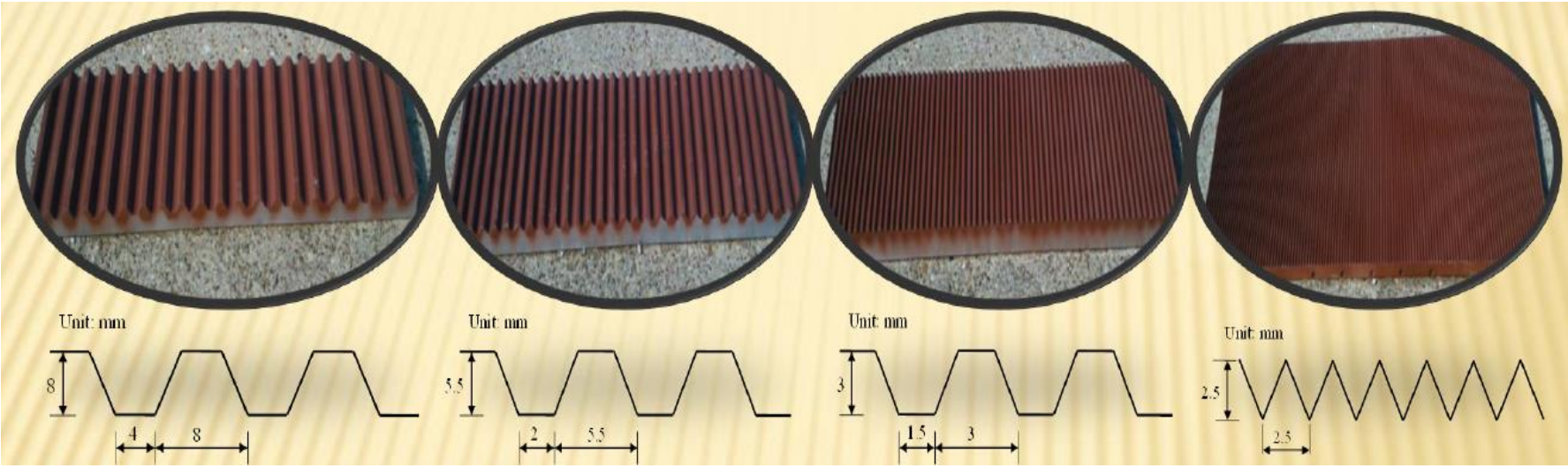
Use step gauge to record/evaluate depth measurement accuracy

↓

Use groove gauge to record/evaluate texture measurement accuracy

Validation Board (TxDOT)

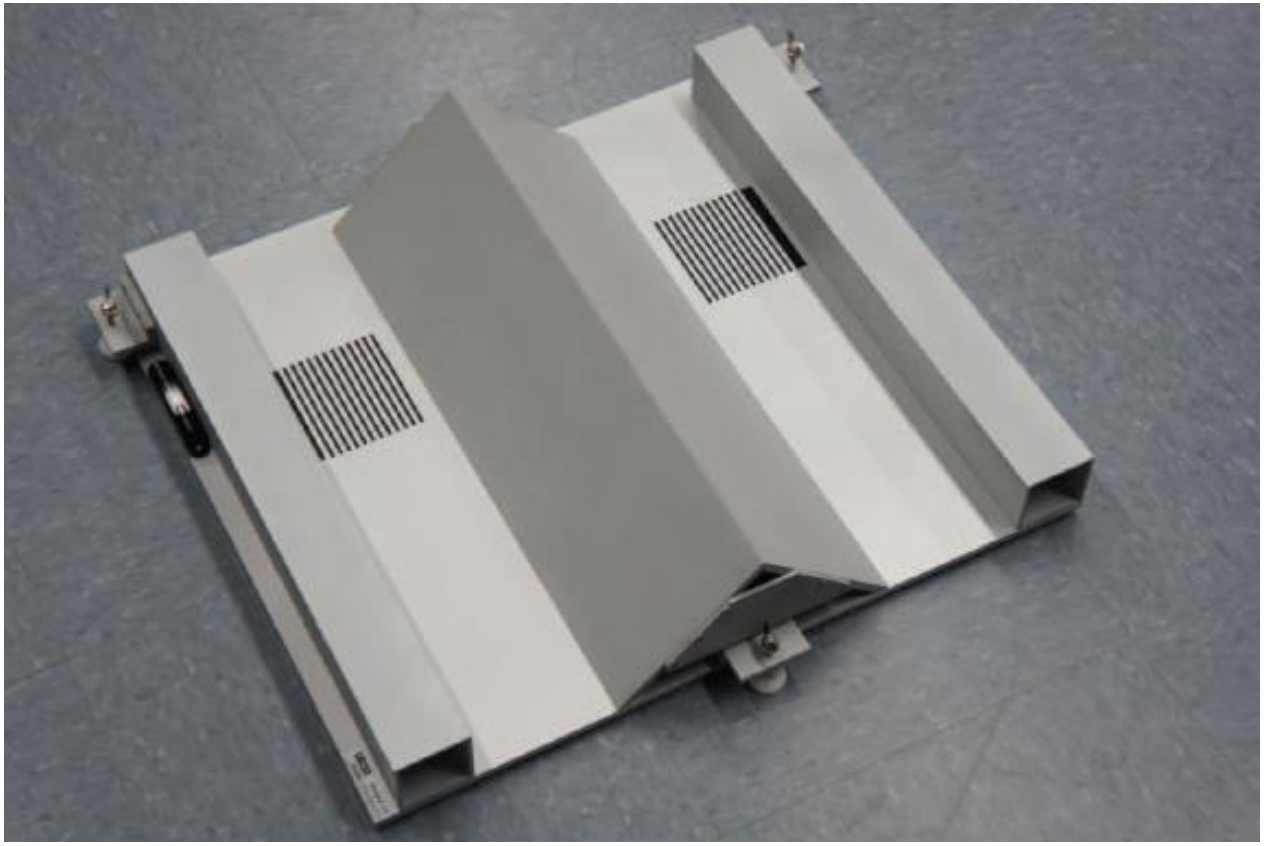
- Developed by TxDOT to validate the texture measurement (MPD) accuracy at different vehicle speeds with different camera exposure times.



Huang, Y., Copenhaver, T., Hempel, P., and Mikhail, M. "Development and Field Evaluation of a Texture Measurement System Based on Continuous Profiles from 3D Scanning System, *2013 TRB Annual Meeting*, Washing, D.C.

Validation Board (Pavemetrics)

- Developed by Pavemetrics to validate the calibration of LCMS (x, z, noise level and focus quality).



(Courtesy of Pavemetrics)

Validation of Derived Data (1)

- Pavement rut depth measurement
  - Establish ground truth using in-lab tests and/or field tests
  - Automatically calculate rut depths using 3D laser data
  - Compare the ground truth and the 3D-laser-data-derived results (accuracy and/or repeatability)
  - Georgia Tech performed in-lab and field tests
  - TxDOT performed large-scale field tests
  - Fugro compared LRMS results with the ones measured by the Transverse Profile Beam (TPB), and the ones derived by both TPB and the Greenwood Laser Profilometer (GLP)

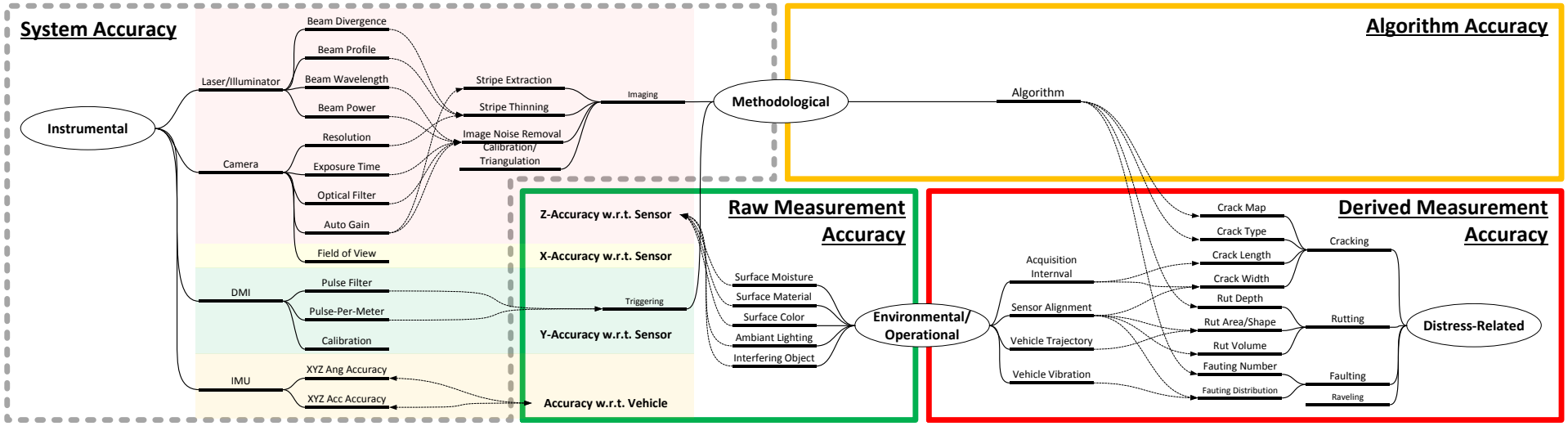
Huang, Y., Copenhaver, T., and Hempel, P. (2013). "Texas Department of Transportation 3D Transverse Profiling System for High-Speed Rut Measurement." *Journal of Infrastructure Systems*, 19(2), 221–230
Erskine, J. (2012). "Determination of Rut Depths from Multi-point Transverse Profile Filtering of Laser Projectin Systems." 25th ARRB Conference – Shaping the future: Linking policy, research and outcomes, Perth, Australia 2012.

Validation of Derived Data (2)

- Crack detection
  - Establish ground truth using in-lab tests and/or field tests
  - Automatically detect cracks using 3D laser data
  - Compare the ground truth and the 3D-laser-data-derived results (accuracy and/or repeatability)
  - Georgia Tech performed in-lab and field tests
    - Used a buffered Hausdorff distance method to quantify the detection accuracy of individual cracks against ground truth
    - Compared crack detection accuracy with different crack widths and different lighting conditions
    - Compared crack width measurement accuracy
  - Ouyang, et al. used total crack length to evaluate crack detection accuracy and repeatability
  - Wang, et al. used crack index to compare the automatic/semi-automatic crack detection results with manual results

Ouyang, W. and Xu, B. (2013). "Pavement Cracking Measurements using 3D Laser-Scan Images." Measurement Science and Technology, 24(2013), 105204.
Wang, K. C. P., Hou, Z., and Williams, S. (2011). "Precision Test of Cracking Surveys with the Automated Distress Analyzer." Journal of Transportation Engineering, 137(8), 571-579.

Proposed Roadmap



Summary

- 3D laser data has broad application to automatically extract pavement condition data including cracking, rutting, raveling, texture, and smoothness
- Inherent noise and noise from data collection process could affect the accuracy of data utilization
- Highway agency has no a standard procedure to validate the data accuracy and repeatability
- It is suggested to use a standardized validation board to directly validate range measurement accuracy following a standard procedure

Thanks!

Q/A

Backup Slides

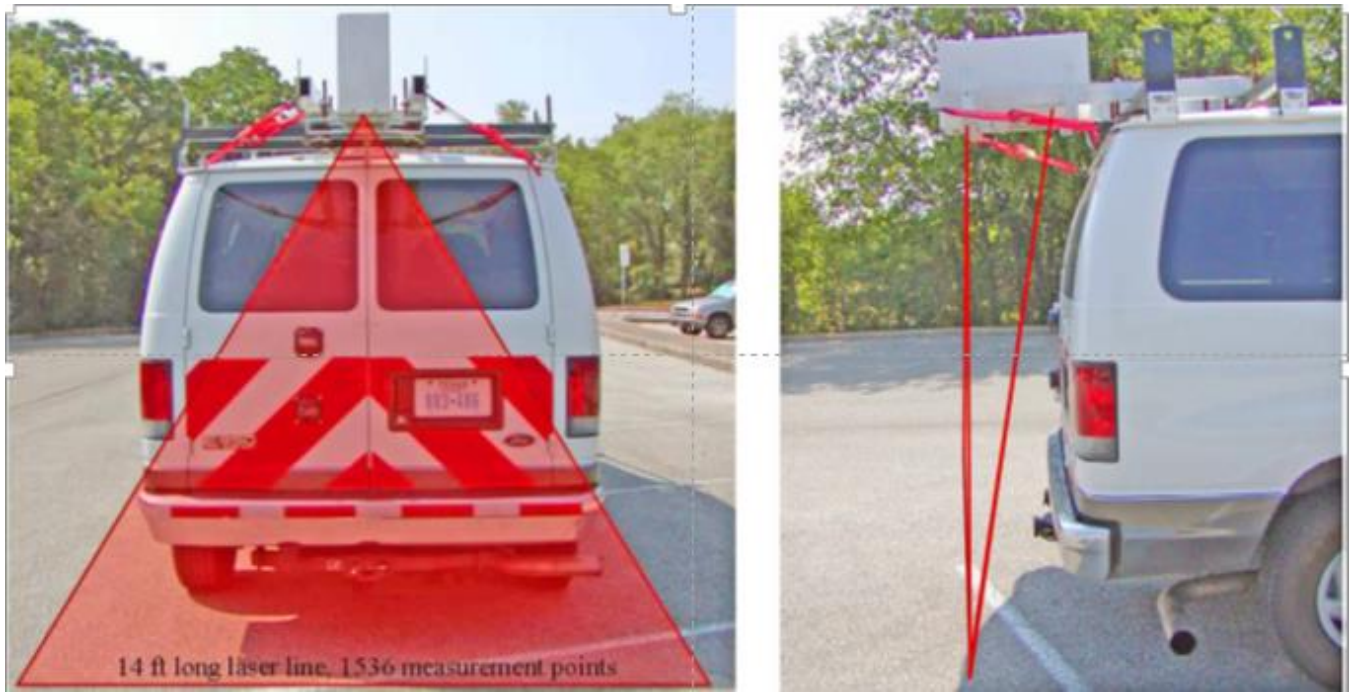
Examples of 3D Laser System

Georgia Tech Sensing Vehicle

Pathway 3D Imaging

http://www.pathwayservices.com/3D_imaging.shtml

TxDOT VRUT System



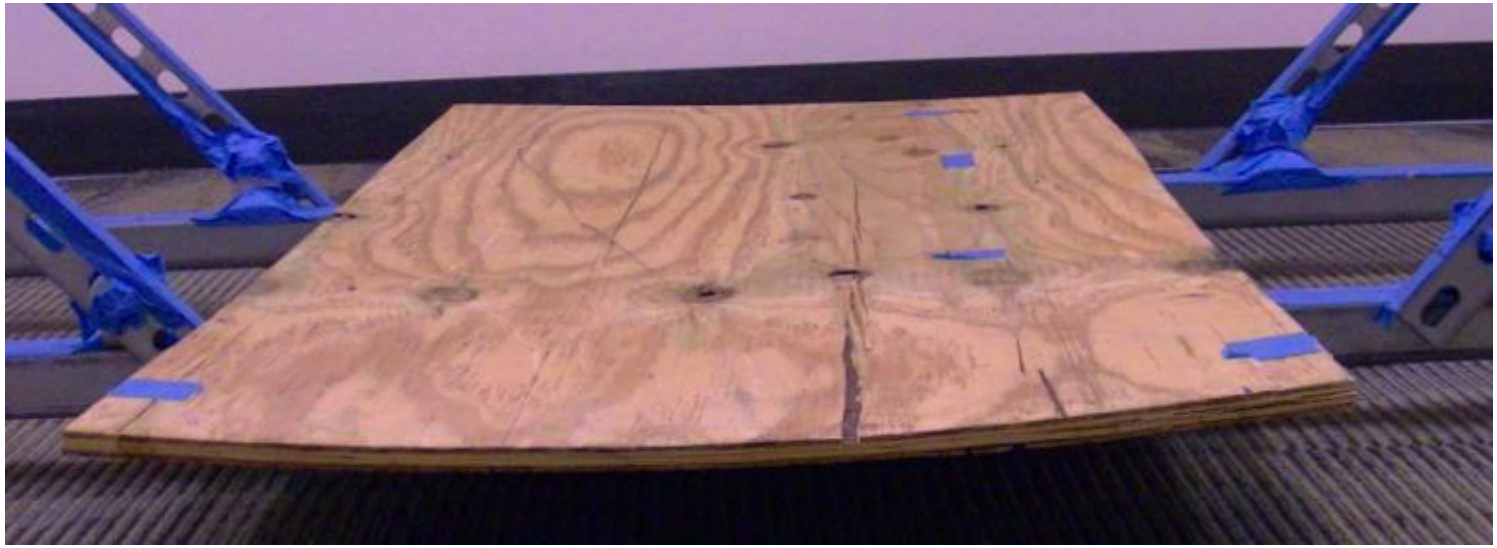
Huang, Y., Copenhaver, T., and Hempel, P. (2013). “Texas Department of Transportation 3D Transverse Profiling System for High-Speed Rut Measurement.” Journal of Infrastructure Systems, 19(2), 221–230

Waylink DHDV

http://www.waylink.com/dhdv.htm

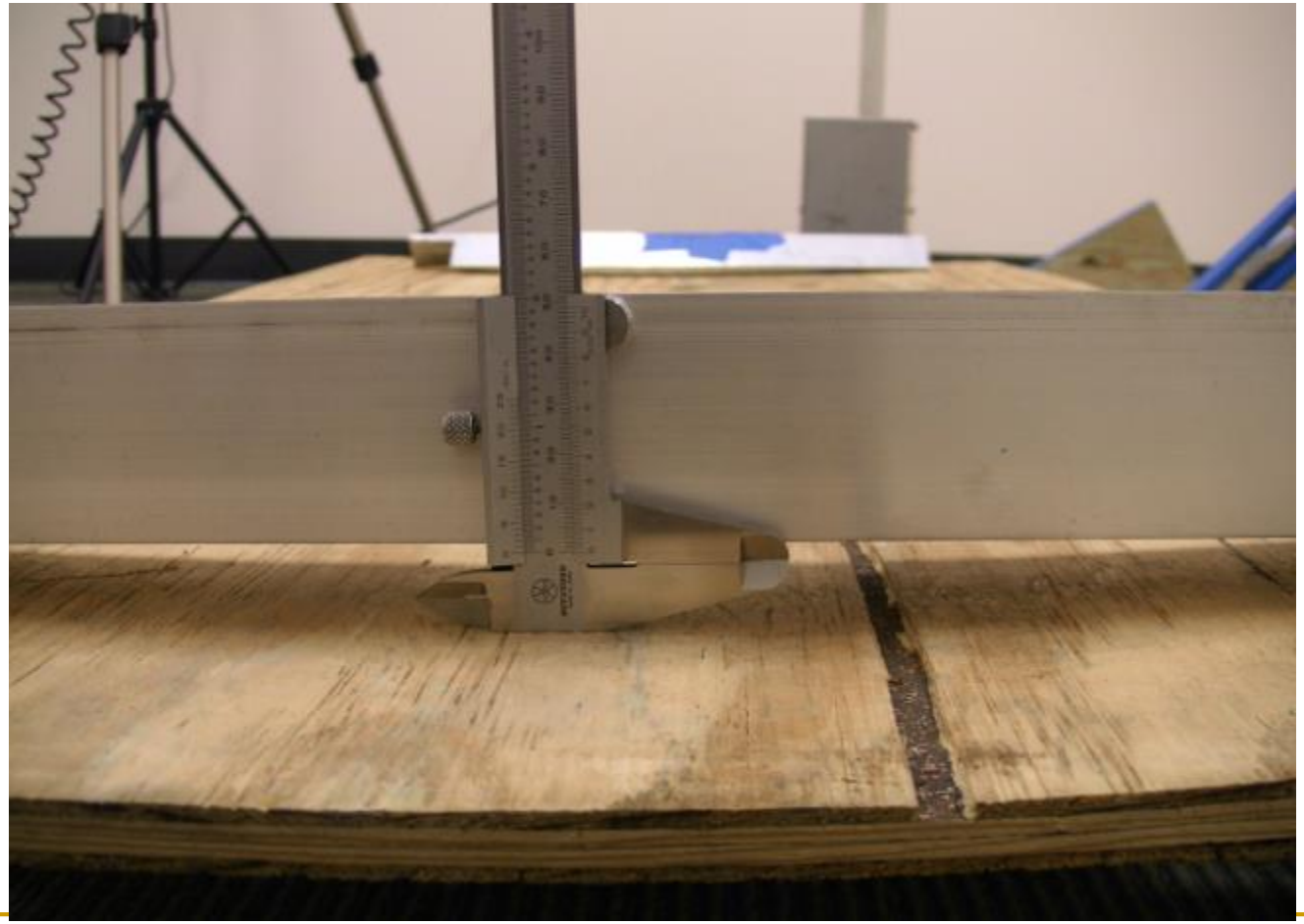
Validation of Rut Depth Measurement

In-Lab Test – Test Samples



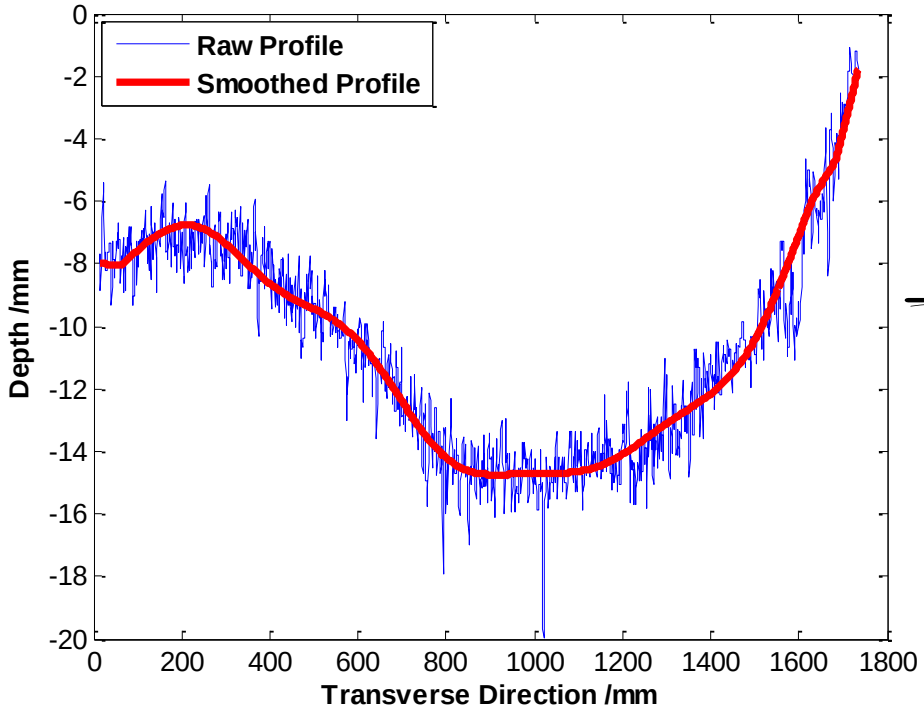
Tsai, Y. C. and Wang, Z. (2013). “A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS).” Final Report for USDOT project: DTOS59-10-H-0003.

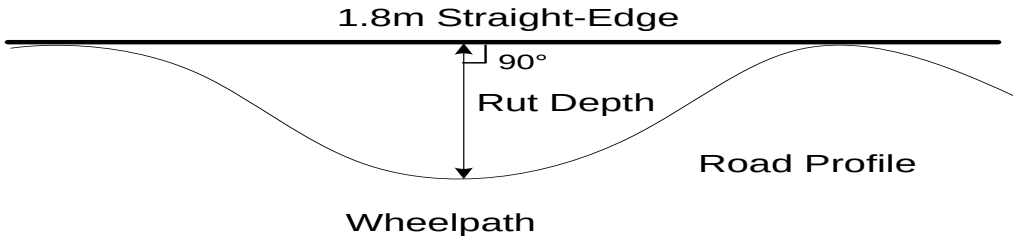
In-Lab Test – Manual Measurement



Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

Rut Depth Calculation





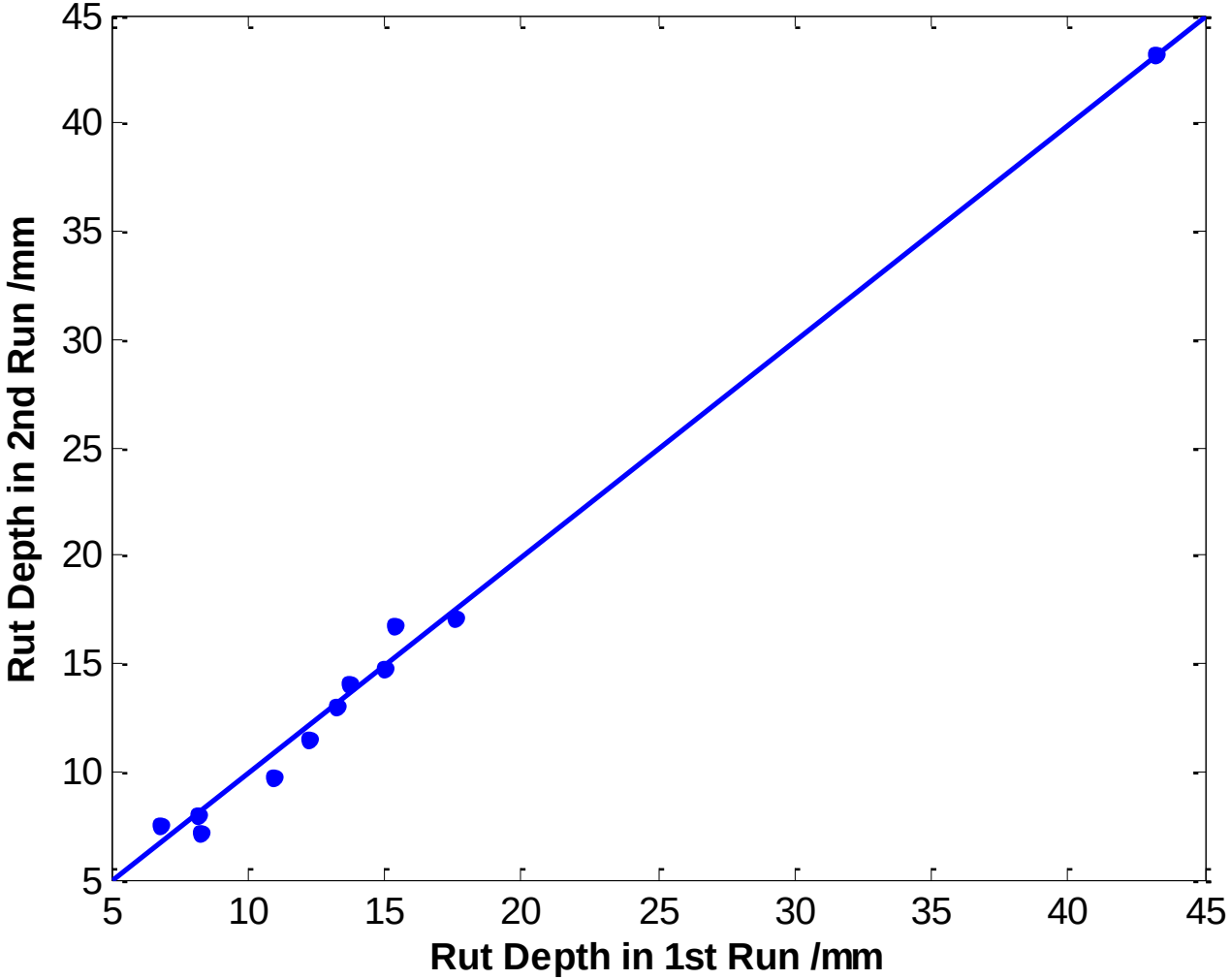
Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

In-Lab Test - Results

Profile #	Severity Level	Rut Depth (mm)					
		Ground Truth	3D Line Laser Measured				Difference to Ground Truth
			1st Run	2nd Run	Difference between Runs	Average	
1	Low	8.0	8.3	7.1	1.2	7.7	0.3
2	Low	7.9	8.2	8.0	0.2	8.1	-0.2
3	Low	7.9	6.8	7.6	0.8	7.2	0.7
4	Medium	13.2	13.2	13.1	0.1	13.2	0.0
5	Low	12.3	12.3	11.5	0.8	11.9	0.4
6	Medium	14.2	13.8	14.0	0.2	13.9	0.3
7	Medium	15.5	15.0	14.8	0.2	14.9	0.6
8	Medium	16.2	15.4	16.7	1.3	16.1	0.1
9	Medium	17.5	17.6	17.1	0.5	17.4	0.1
10	Medium	10.0	11.0	9.7	1.3	10.4	-0.4
11	High	43.4	43.2	--	--	43.2	0.2

Tsai, Y. C. and Wang, Z. (2013). “A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS).” Final Report for USDOT project: DTOS59-10-H-0003.

In-Lab Test – Results (Cont'd)



Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

Field Tests – Rut Depth Measurement

- Two test sites; 10 selected profiles

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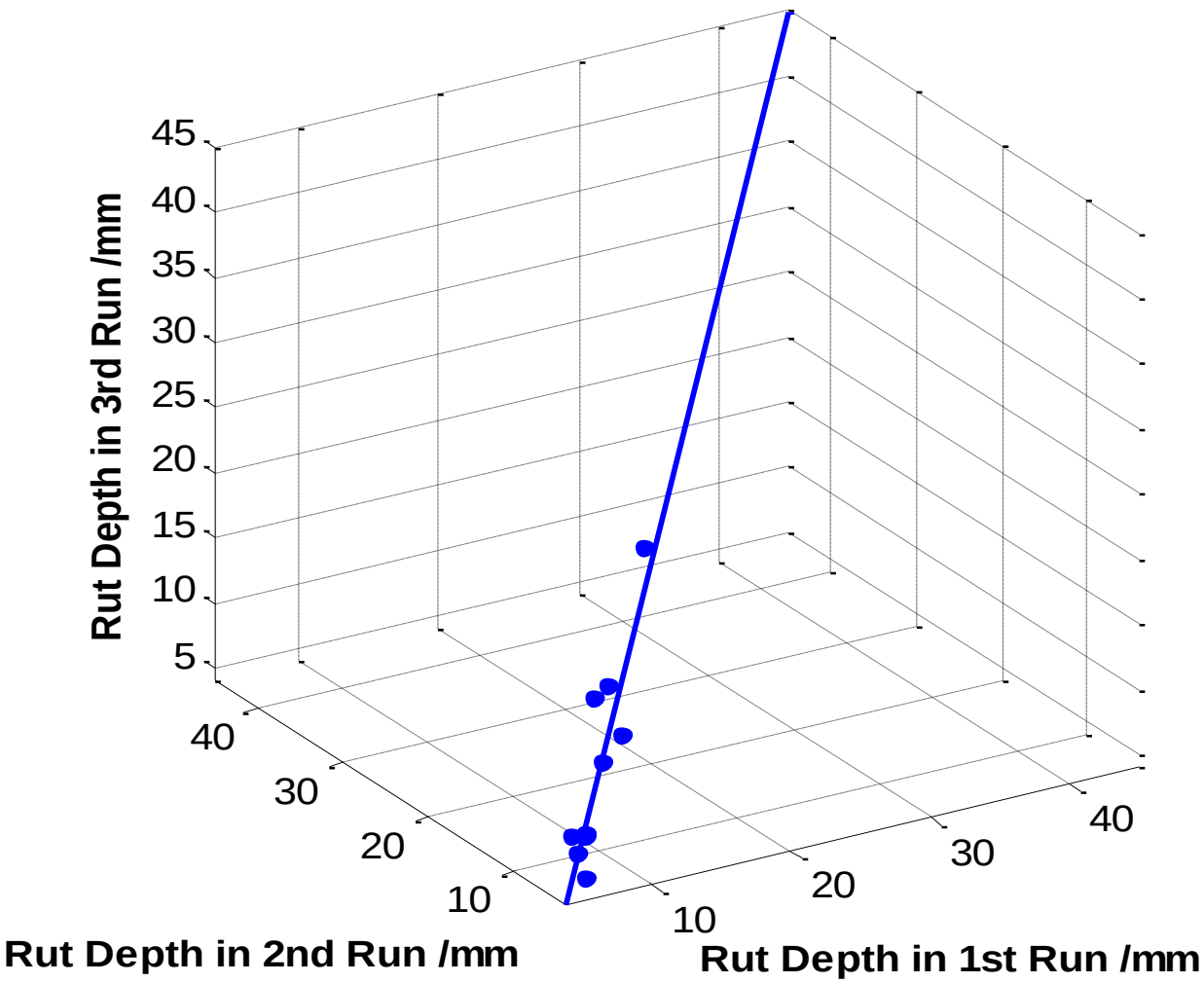
Field Tests - Results

Profile #	Severity Level	Rut Depth (mm)					
		Ground Truth	3D Line Laser Measured				Difference to 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	High	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

Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

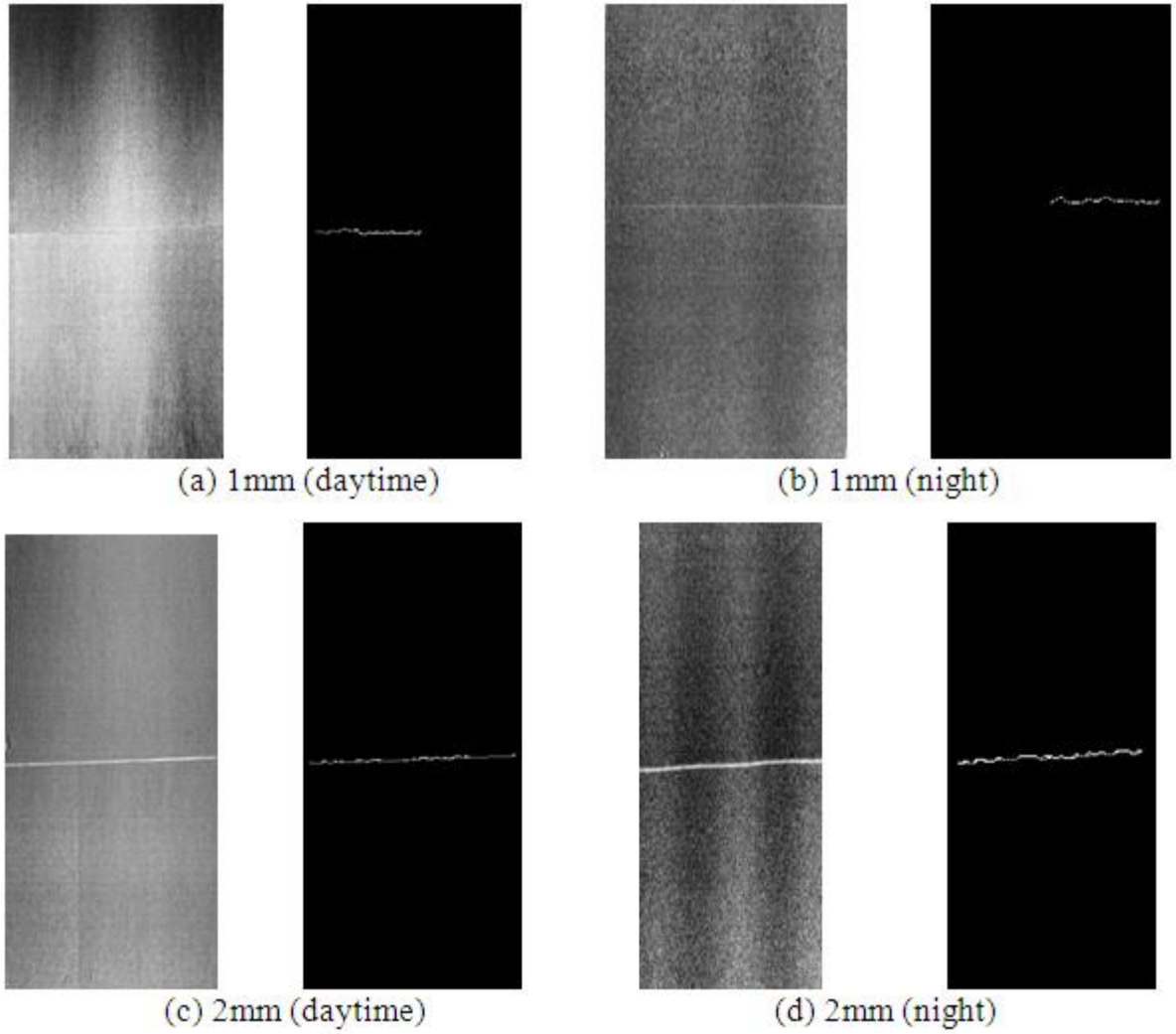
Field Test - Results (Cont'd)



Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

Validation of Crack Detection and Crack Width Measurement

Laboratory Test Results for Crack Detection



(a) 1mm (daytime)

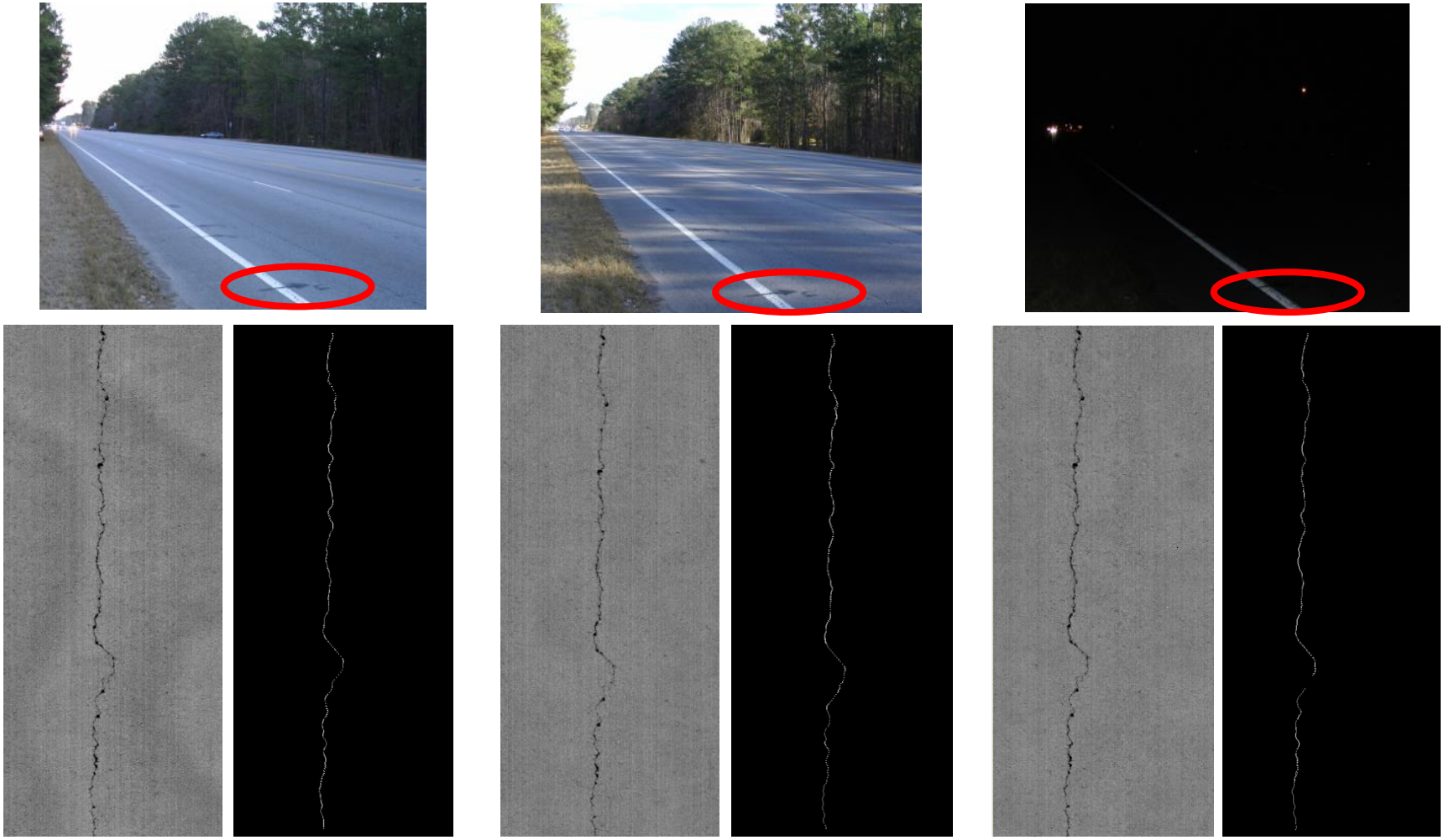
(b) 1mm (night)

(c) 2mm (daytime)

(d) 2mm (night)

Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

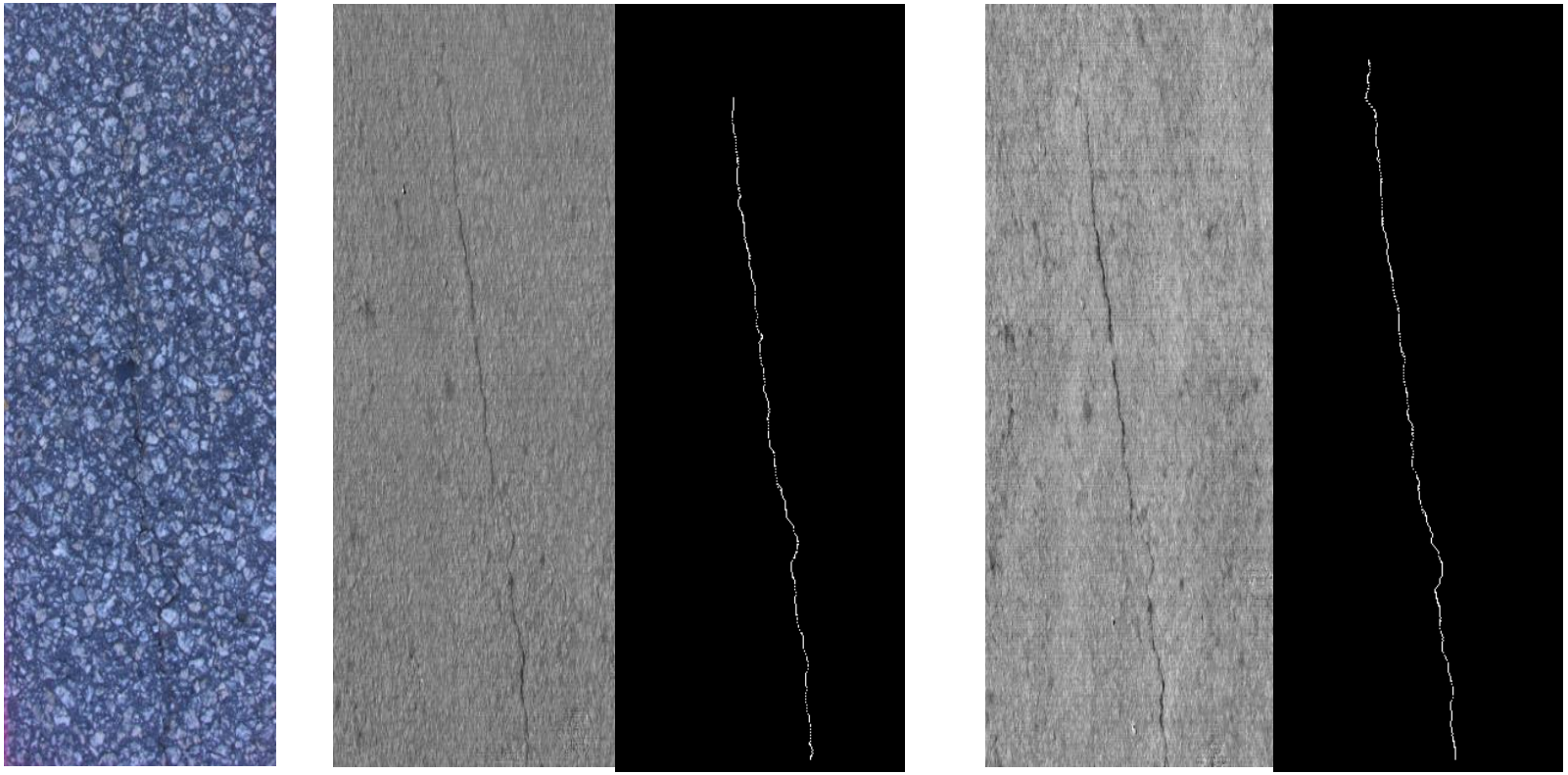
Field Test #1 - Different Lighting Conditions



Daytime (no shadow) Shadow Night

Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

Field Test #2 - Low Intensity Contrast Condition

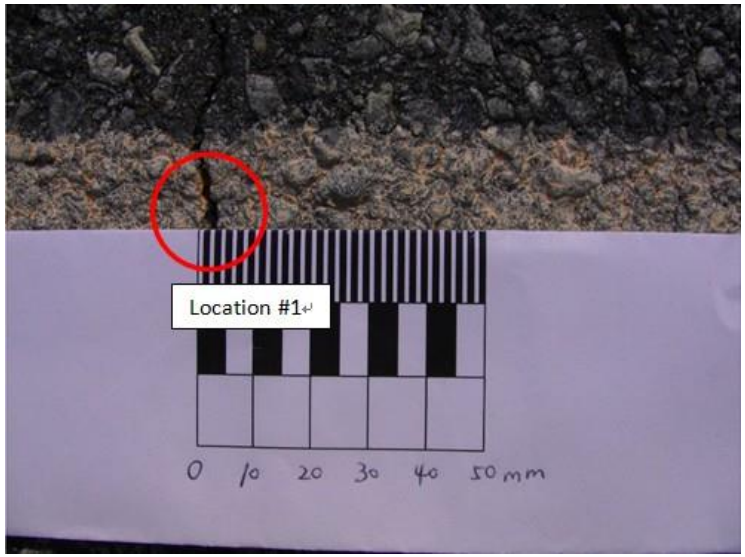


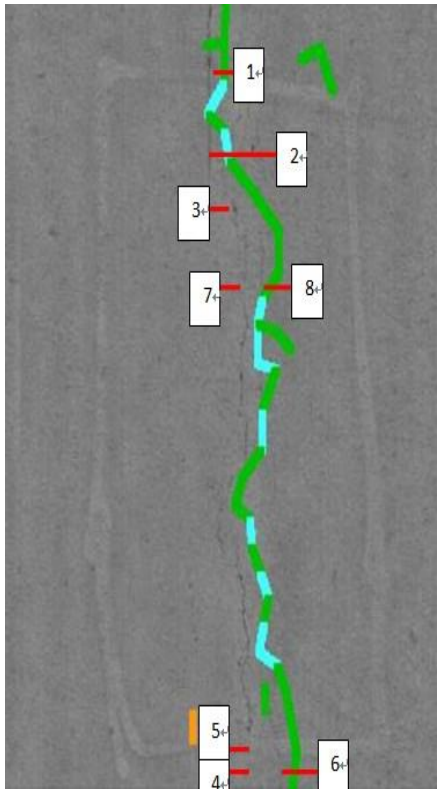
Daytime (score = 98.3) **Night (score = 98.0)**

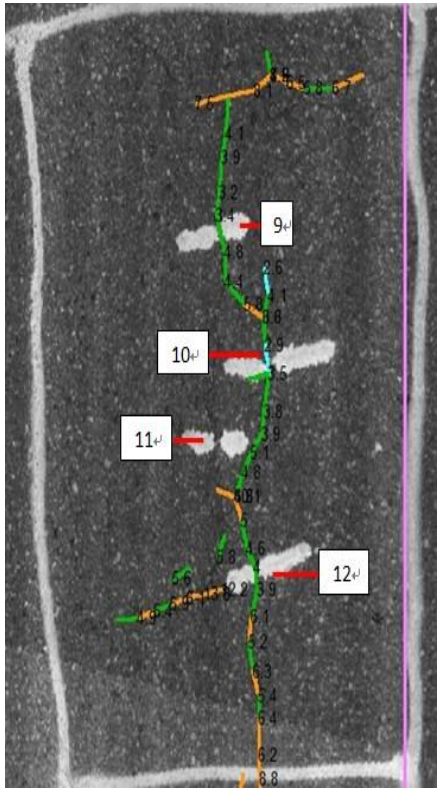
Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

Crack Width Measurement

- Experimental Test
  - Data Source: SR275, Mile 1-2, 12 selected spots.







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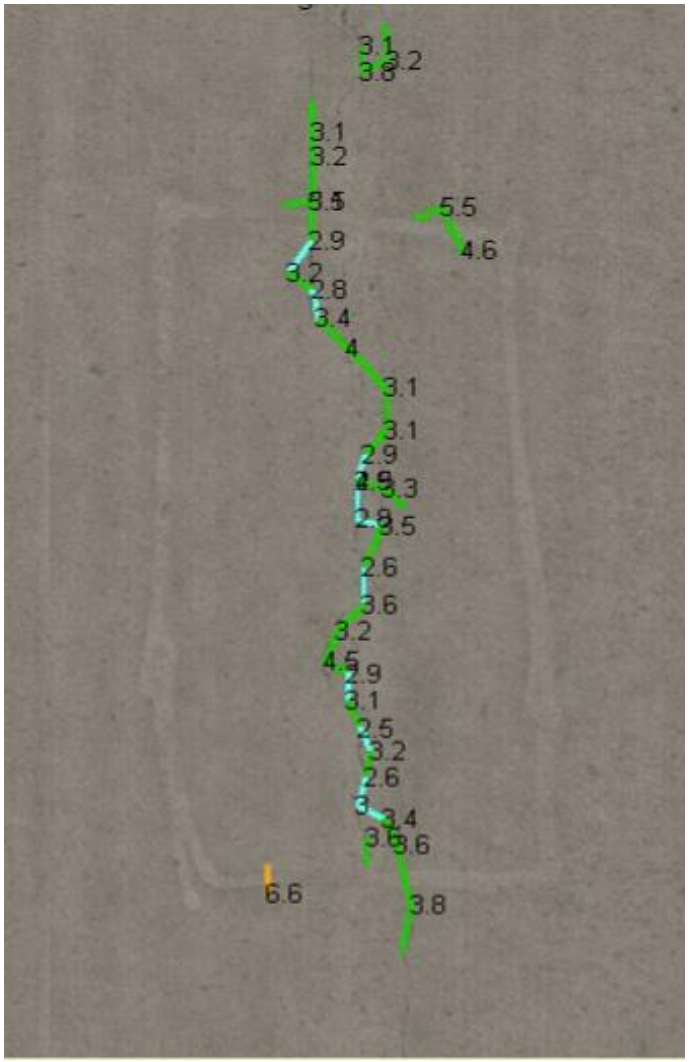
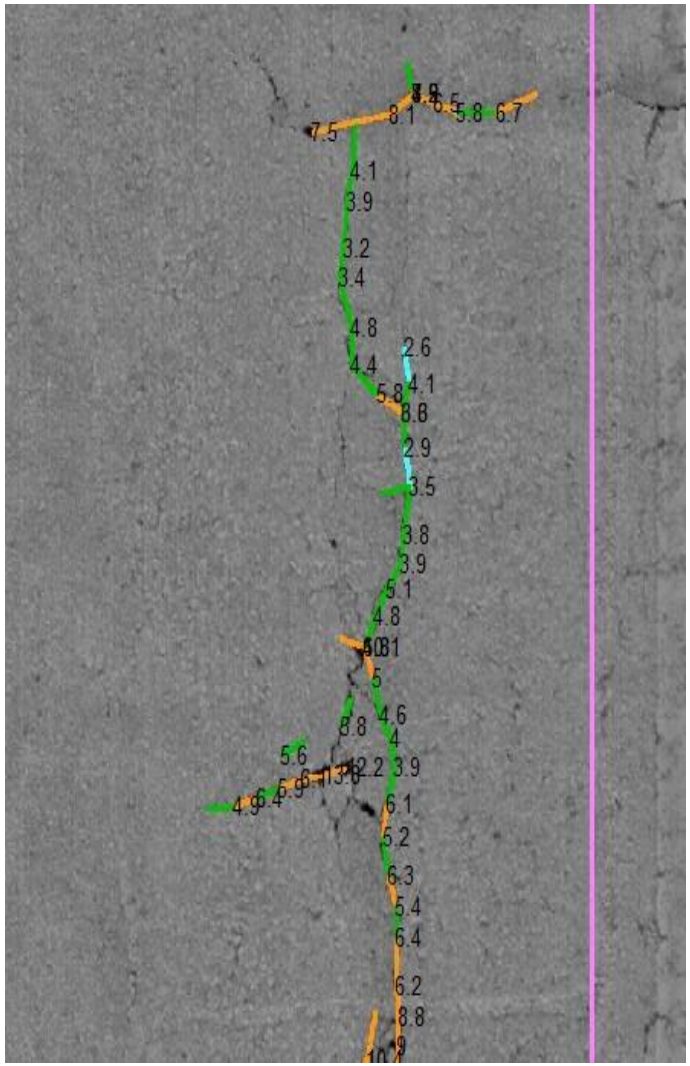
Crack Map with Width Information





Tsai, Y. C. and Wang, Z. (2013). “A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS).” Final Report for USDOT project: DTOS59-10-H-0003.

Experimental Results

Location No.	LCMS Crack Width (mm)	Manually Measured Crack Width (mm)	Absolute Difference (mm)
1	3.5	3.5	0
2	2.8	3.0	0.2
3	4	3.5	0.5
4	Not detected	1.5	N/A
5	Not detected	1	N/A
6	3.8	3	0.8
7	Not detected	1	N/A
8	3.1	3	0.1
9	4.8	4	0.8
10	2.9	3	0.1
11	Not detected	1	N/A
12	4	5	1
Avg. (detected)	3.6	3.5	0.4

Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.