June 2, 2015

TPF-5(299) Technical Advisory Committee (TAC) and Friends Webinar Meeting Minutes

2 -3:30 pm EST

- Opening Comments, Mergenmeier, FHWA, the 2 presentations (attached) are from work funded by the Pooled Fund Study (PF).
- Presentations
    - Tsai, GaTech, Technology Overview on Validating 3D Transverse Profile Data and Measurement of Pavement Surface Distress, 30 minutes
    - Ferris, VaTech, Transverse Profile Demonstration, 15 minutes
- Other Related Projects, Mergenmeier, FHWA,
    - Funded by PF: RFP for Standard Data Format, advertised May 8; Proposals due June 8;
    - NCHRP project, Defining Comparable Cracking Data – contract has not been executed as of today.
    - Proposed NCHRP project on pavement surface macrotexture, status – if approved for funding and following standard RFP development process, RFP may be available late 2015.
    - Other projects? None were brought forward.
- Outcomes of TAC meeting, Mergenmeier, FHWA
    - Next in person meeting will be at RPUG, first week of November 2015 in Raleigh, NC. The draft agenda for the various meetings at RPUG is attached. The RPUG planning committee has set aside 1 ½ days for our PF to meet if needed. PF meeting agenda will be developed.
    - PF web presence: PF members approved development of an Internet SharePoint site for PF purposes. The site will have information that will be available to the public and will be set up to have a TAC only restricted area. It is hopeful the site will be ready by RPUG.
    - AASHTO PP 67, Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods. Major revisions were made to PP 67 by a task group of TAC/Friends. The revisions will be submitted to AASHTO for approval. If approved the revised standard will be published in 2016.
    - New projects for PF to undertake. Research Needs Statements from May 2014 were reviewed. The TAC approved development of a RFP type document that includes both Transverse Profile calibration/verification and analysis. It is expected the RFP will be advertised late 2015/early 2016 pending availability of funds.
- Open Discussion – All – no comments

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

**Yichang (James) Tsai, Ph.D., P.E., Professor**
**Zhaohua Wang, Ph.D., P.E., Senior Research Engineer**
**Georgia Institute of Technology**

**June 2, 2015**

# Acknowledgement


- This study was sponsored by the Federal Highway Administration (FHWA).
- The research results from the PIs were part of the research project, entitled Remote Sensing and GIS-enabled Asset Management System (RS-GAMS), sponsored by the U. S. Department of Transportation Office of the Assistant Secretary for Research and Technology (USDOT/OST-R) and the Georgia Department of Transportation (GDOT). Connecticut DOT, Florida DOT, Kansas DOT, Louisiana DOTD, Mississippi DOT, Oklahoma DOT, South Carolina DOT, and Texas DOT provided technical support.

# Acknowledgement (cont'd)


- Other Team Members
  - Dr. Anothny Yezzi, Professor in School of Electrical and Computer Engineering (ECE) at Georgia Tech
  - Yiching Wu, Research Engineer in School of Civil and Environmental Engineering
  - Former Students:
    - Dr. Feng Li; Dr. Chengbo Ai; Dr. Vivek Kaul; Hadrien Glaude; Quentin Caitucoli; Daniel Luh; Josephine Simons; Russel Aziz; Sam Li; Bruno Pop-Stefanow
  - 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

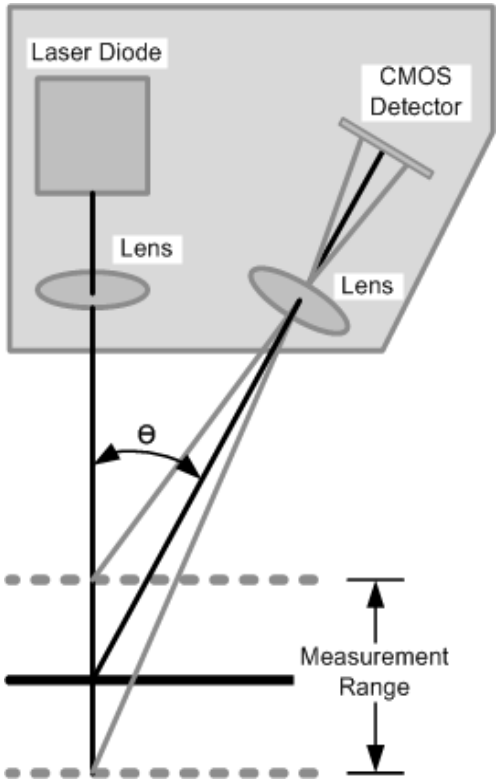
# A Brief History of 3D Laser Scanning

- 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

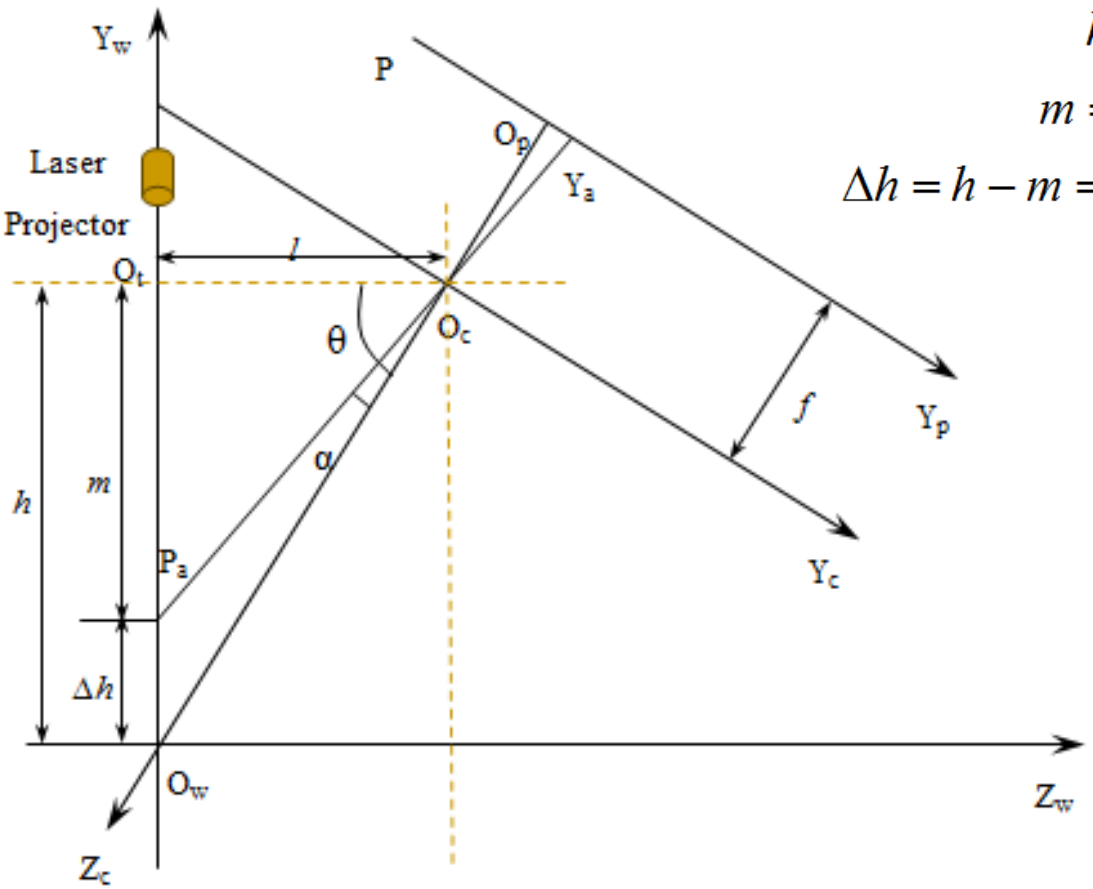
Ebrahim, M. A. (2011) "3D Laser Scanners: History, Applications, and Future" (http://www.researchgate.net).

# 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)




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

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

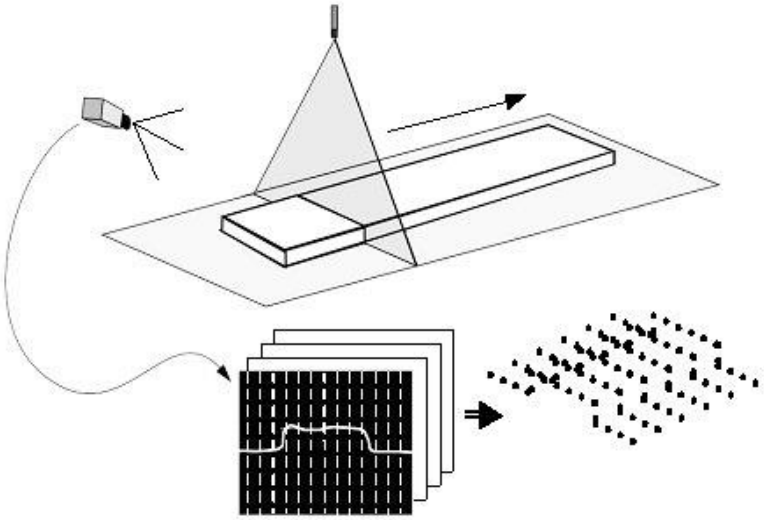
$$m = l \cdot \tan(\theta - \alpha)$$

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

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

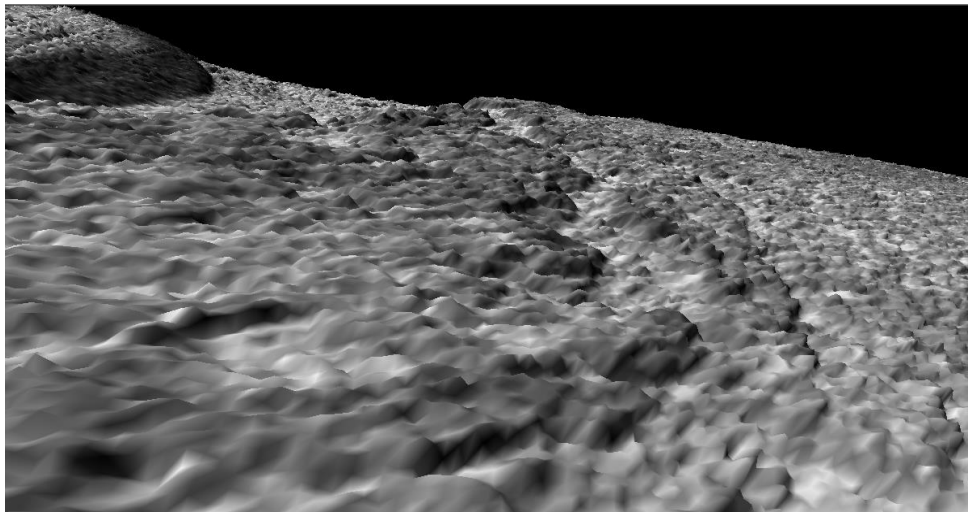


(Laurent, et al., 2008)

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.

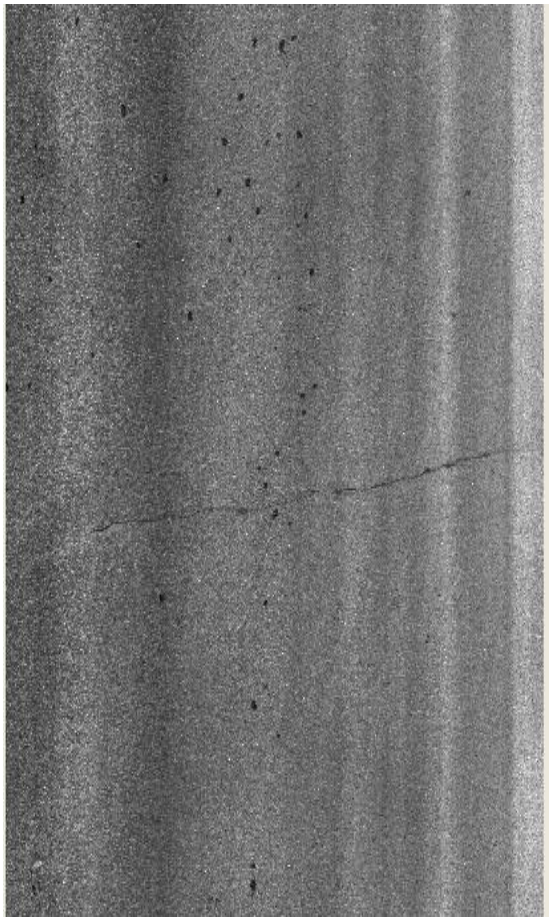


- Resolution
  - Driving dir.: 1 - 5 mm
  - Transverse dir.: 1 mm
  - Elevation: 0.5 mm
  - Data points collected per second and width covered
    - 2 (lasers) * 2048 (points/profile/laser) * 5600 HZ = 22,937,600 points/second

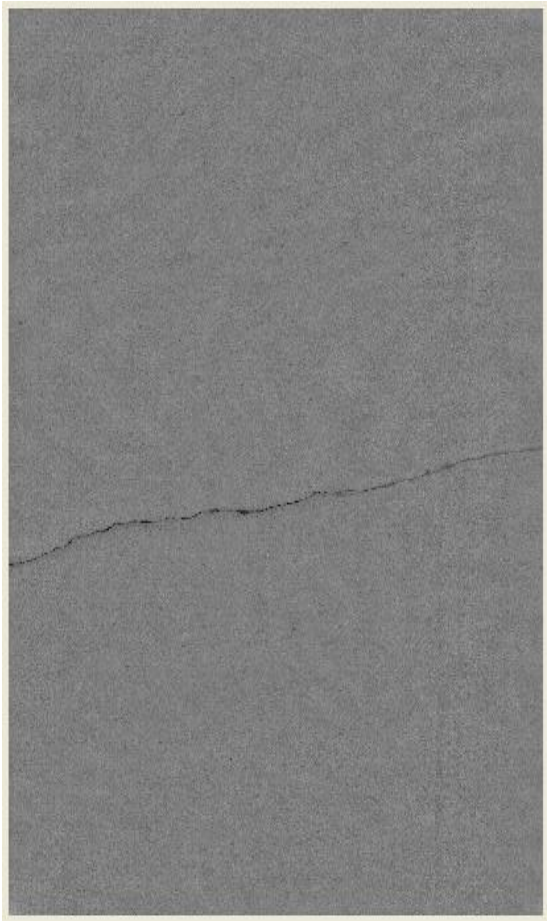
Note: The specification shown above is for the system tested by the PIs.

# Advantage of 3D Data over 2D Data

2D data



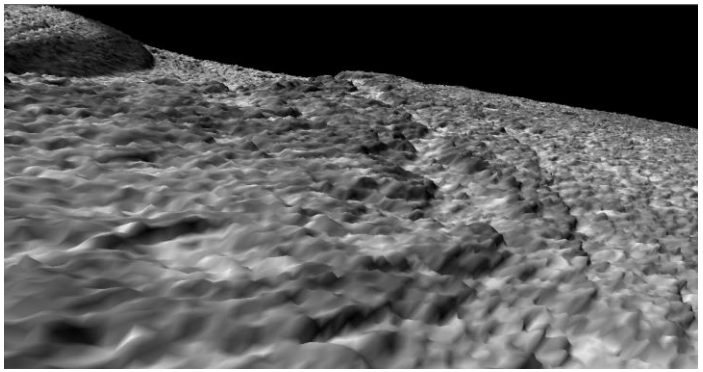
3D data



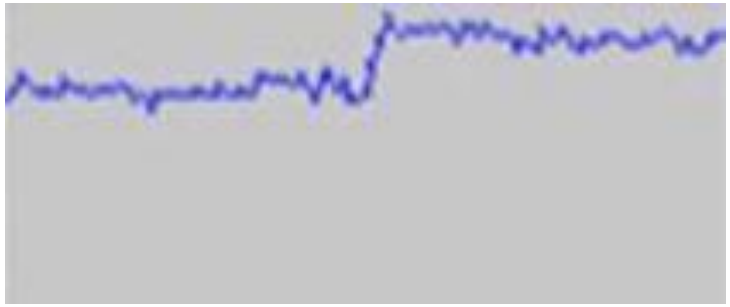
With 3D technology, it is much clearer to distinguish a crack from the surrounding pavements

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.

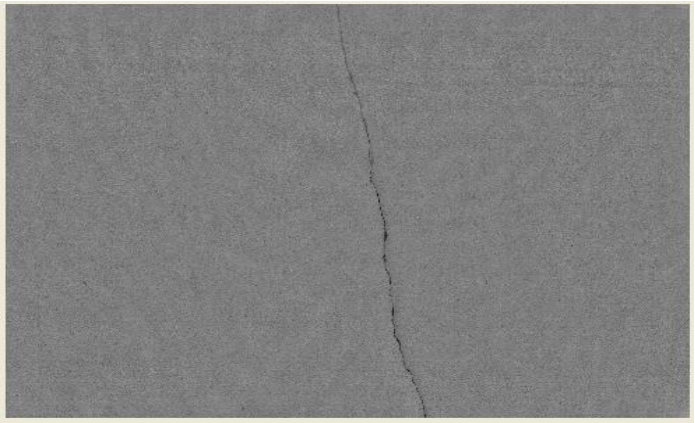
# 3D Laser Data and Its Applications



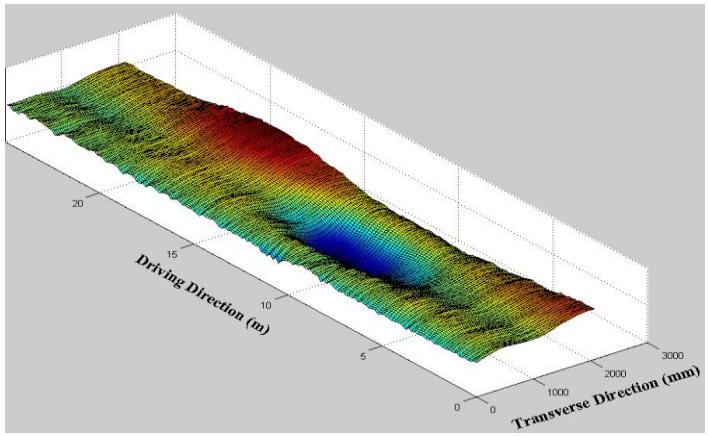
a. Texture



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.

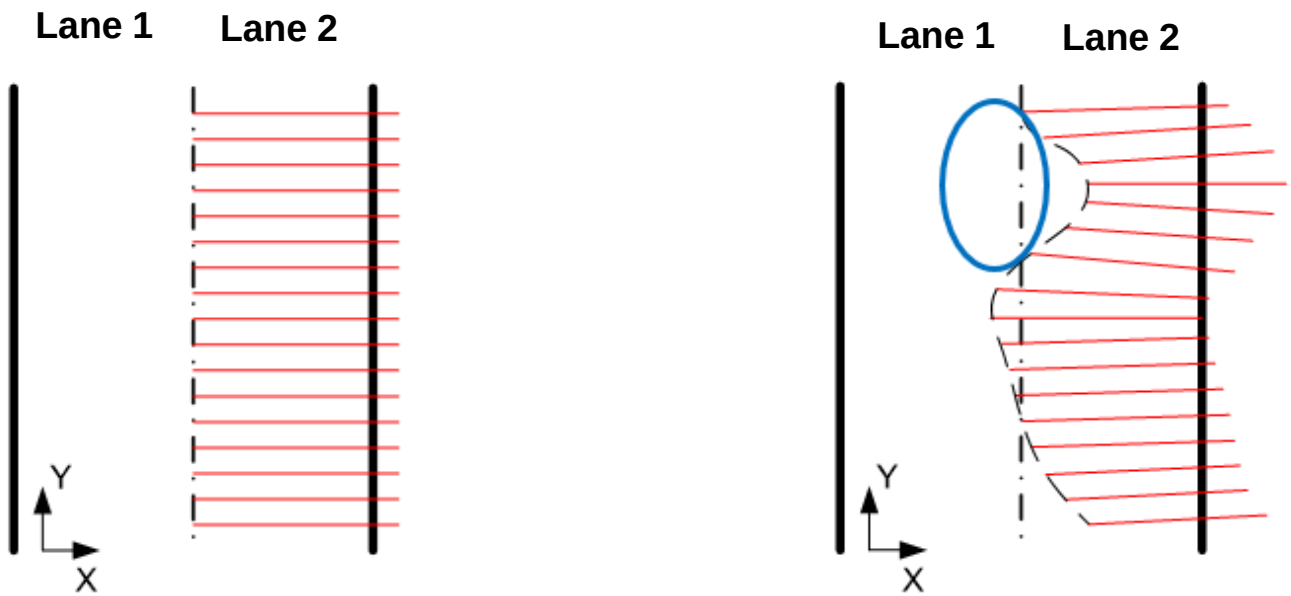
# Characteristics of 3D Range Data (1)

- 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. $\pm 125$ 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



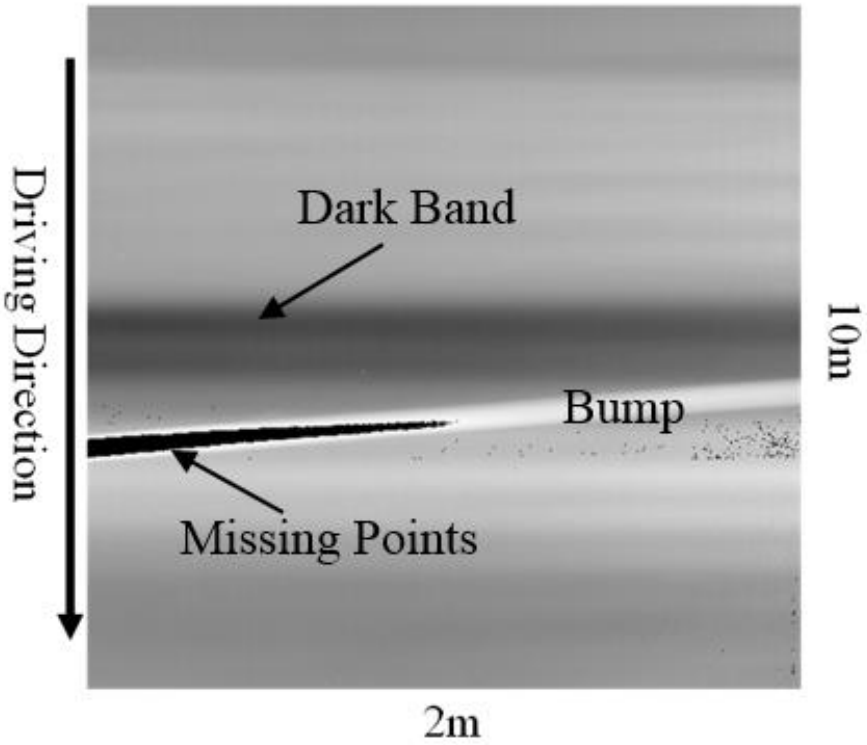

**(a) Ideal case** **(b) Data Collected when Vehicle Moves**

**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

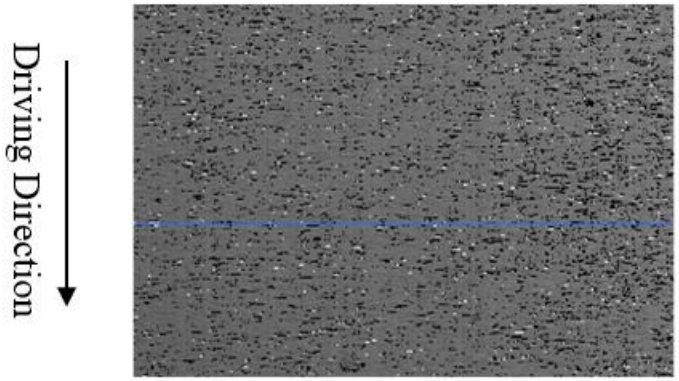


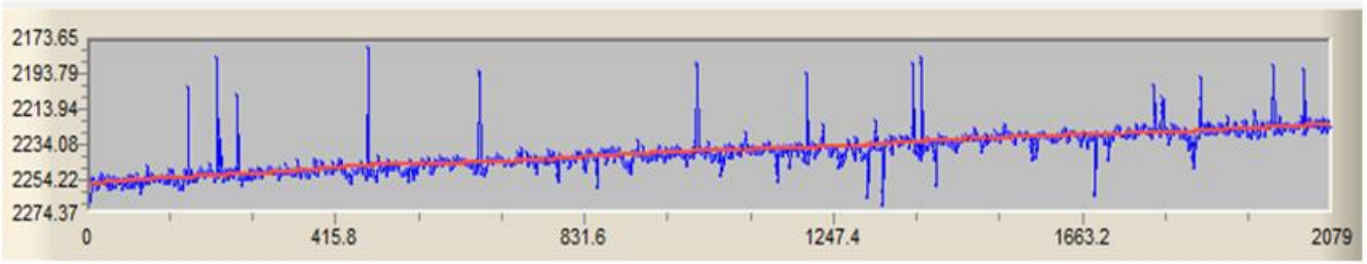

**Data Collected When Passing a Bump**

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)

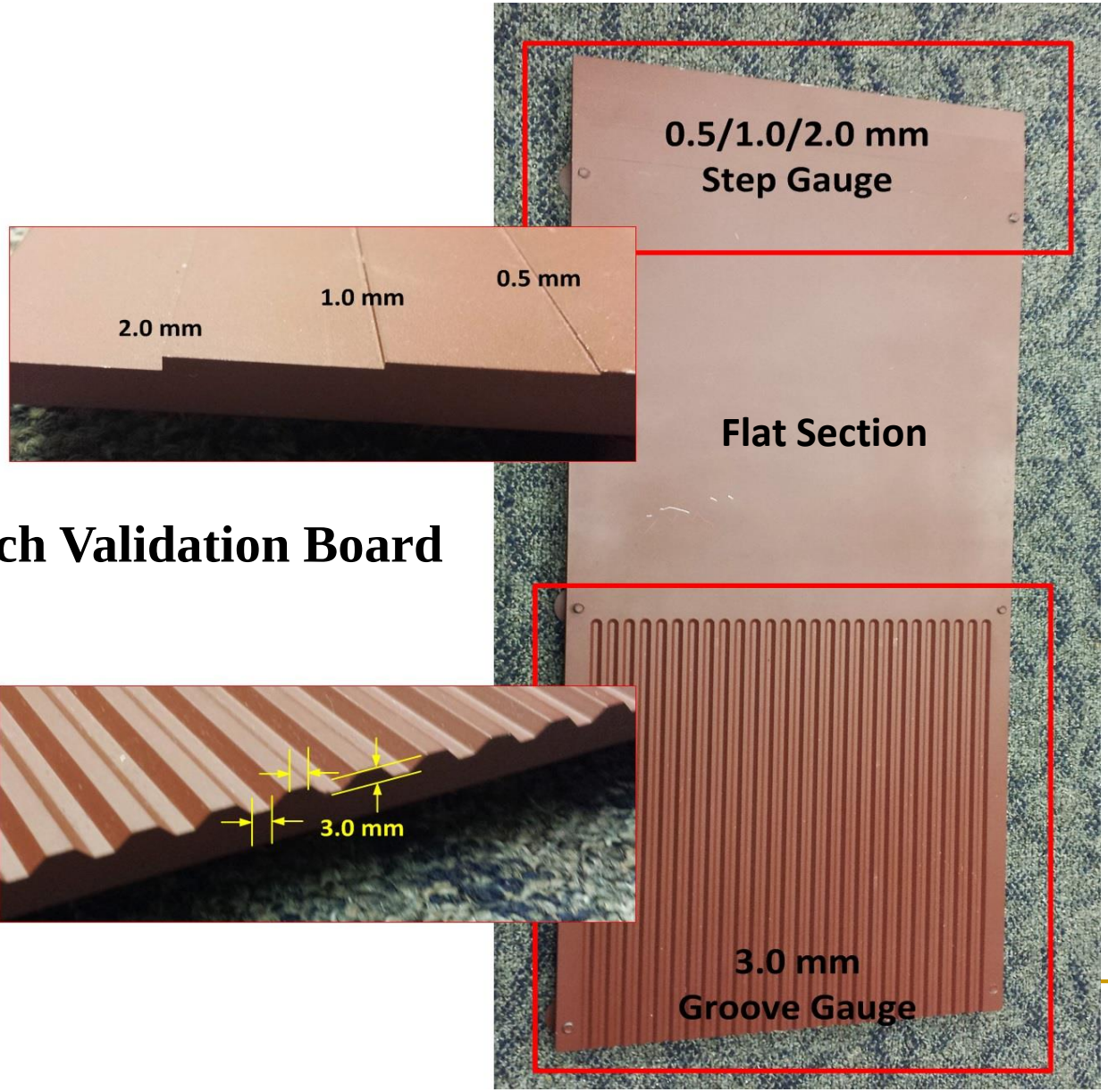
# 3D Calibration

- 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**

↓

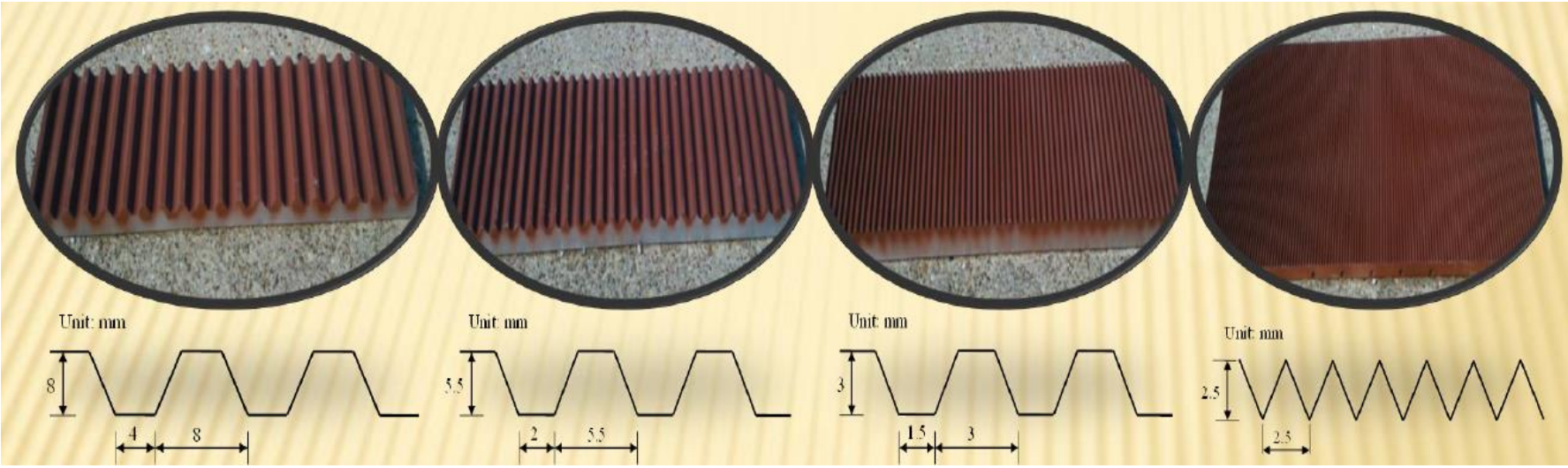
**Use step gauge to record/evaluate depth measurement accuracy**

↓

**Use groove gauge to record/evaluate texture measurement accuracy**

# Validation Board (TxDOT)

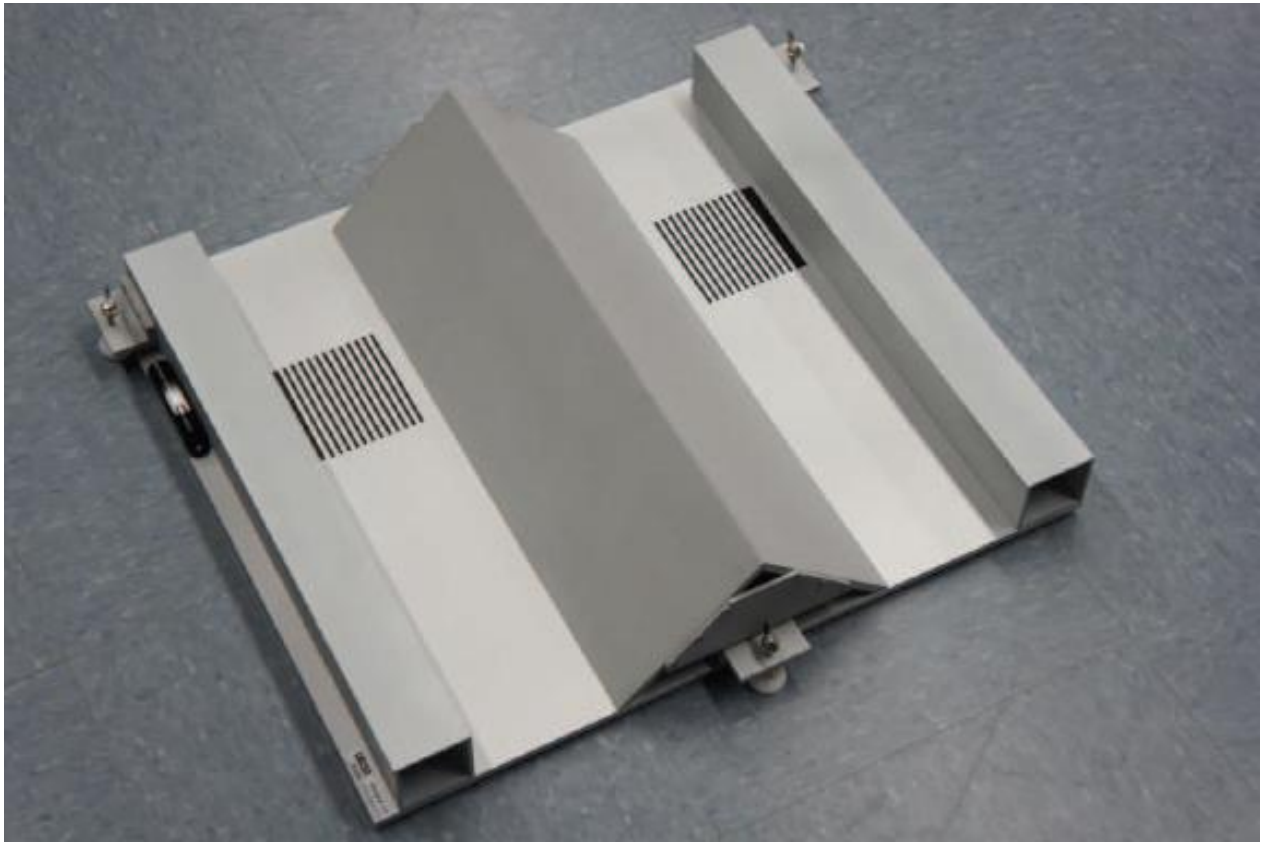
- Developed by TxDOT to validate the texture measurement (MPD) accuracy at different vehicle speeds with different camera exposure times.




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)

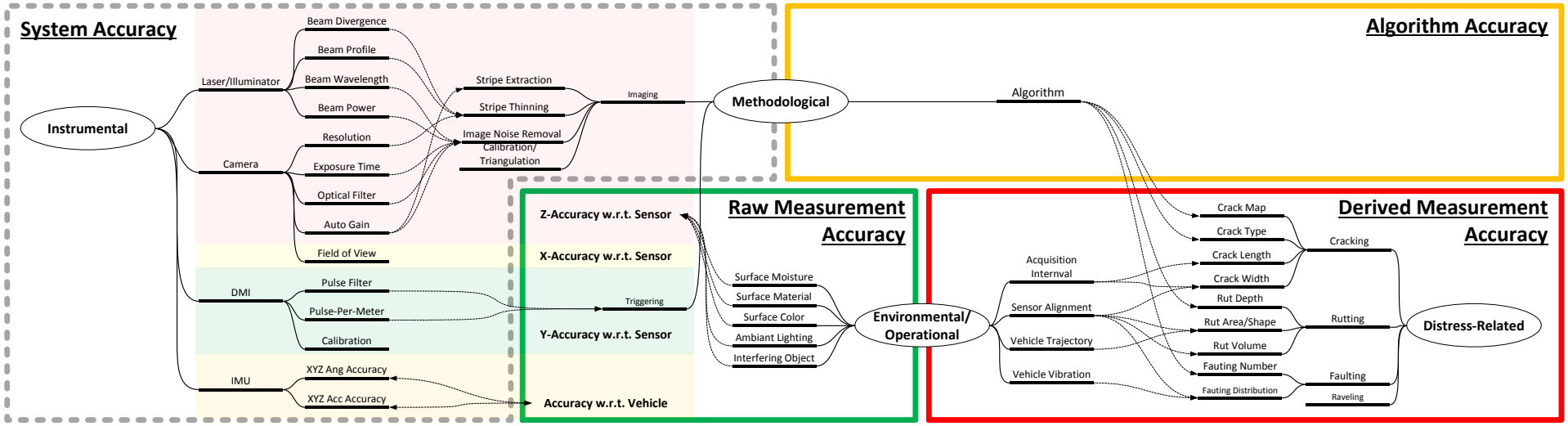
Huang, Y., Copenhaver, T., and Hempel, P. (2013). "Texas Department of Transportation 3D Transverse Profiling System for High-Speed Rut Measurement." *Journal of Infrastructure Systems*, 19(2), 221–230
Erskine, J. (2012). "Determination of Rut Depths from Multi-point Transverse Profile Filtering of Laser 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

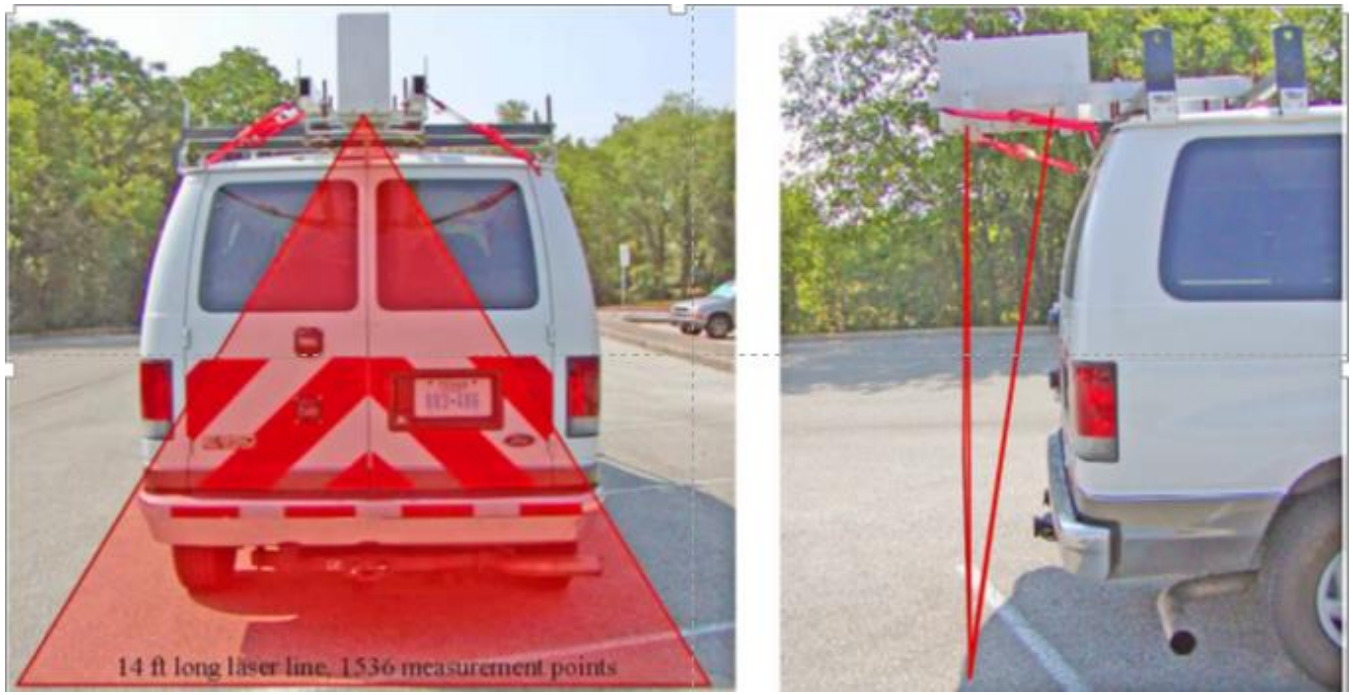
# Examples of 3D Laser System

# Georgia Tech Sensing Vehicle

# Pathway 3D Imaging

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

# TxDOT VRUT System



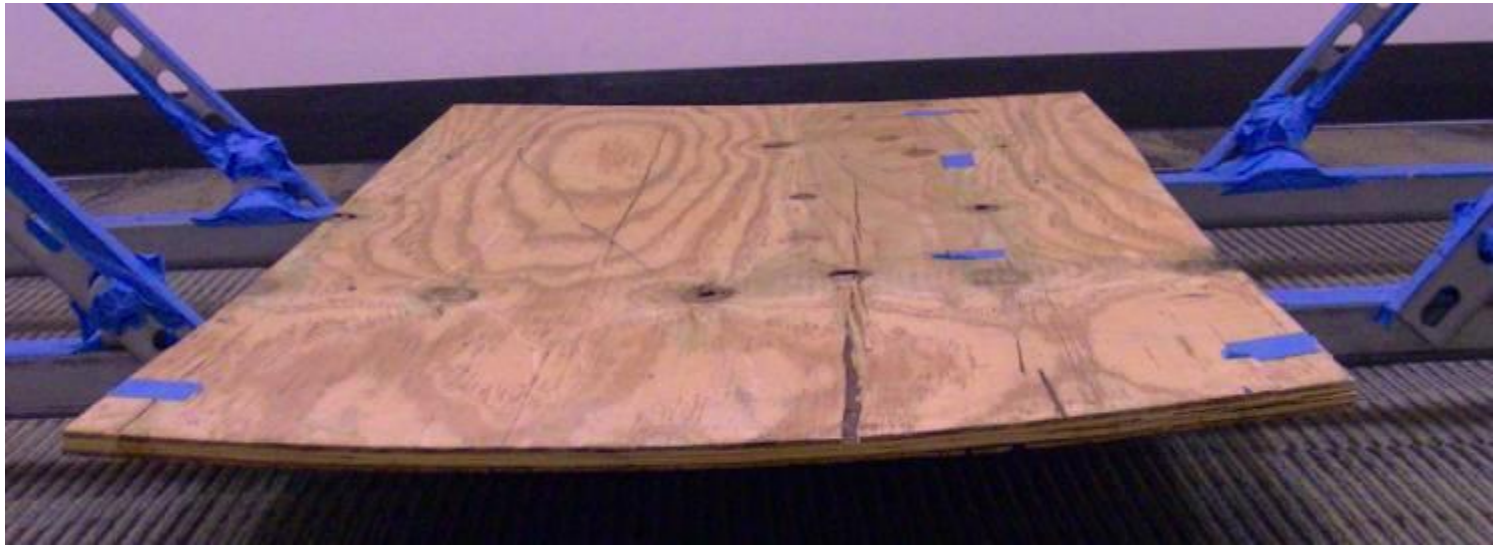

Huang, Y., Copenhaver, T., and Hempel, P. (2013). “Texas Department of Transportation 3D Transverse Profiling System for High-Speed Rut Measurement.” Journal of Infrastructure Systems, 19(2), 221–230

# Waylink DHDV

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

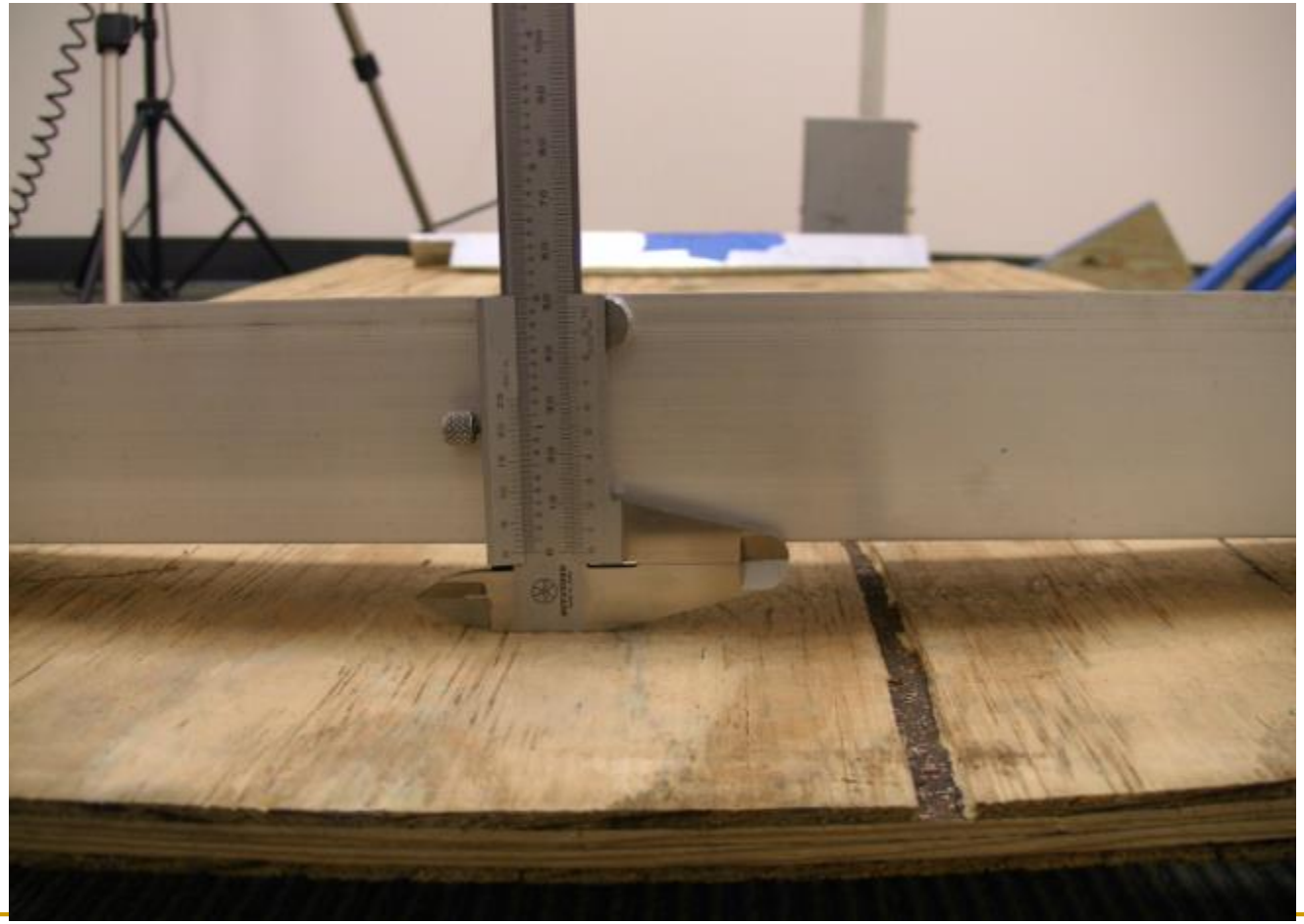
# Validation of Rut Depth Measurement

# In-Lab Test – Test Samples



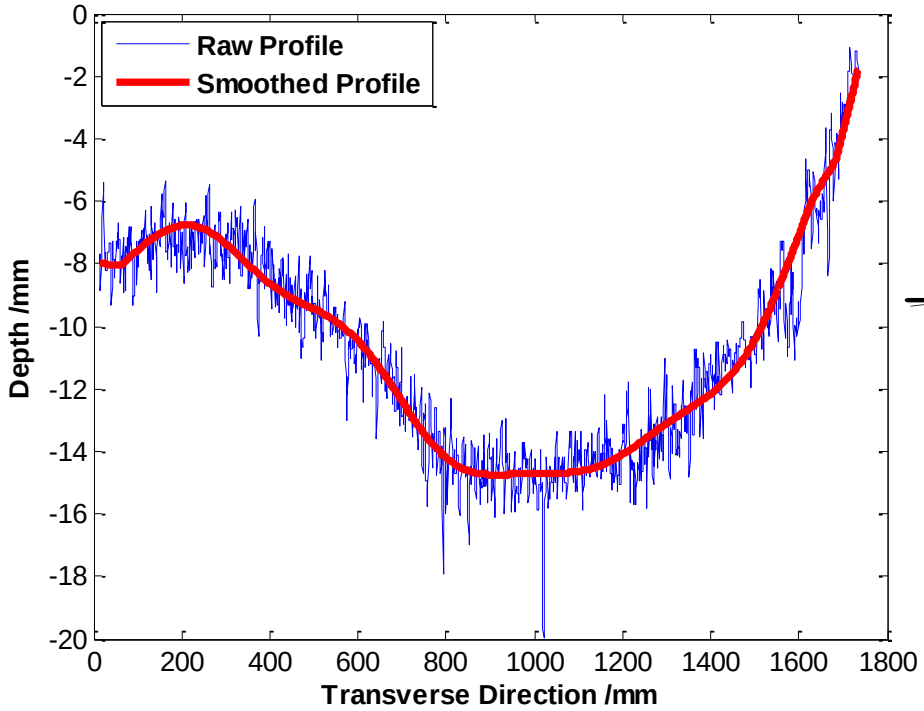
Tsai, Y. C. and Wang, Z. (2013). “A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS).” Final Report for USDOT project: DTOS59-10-H-0003.

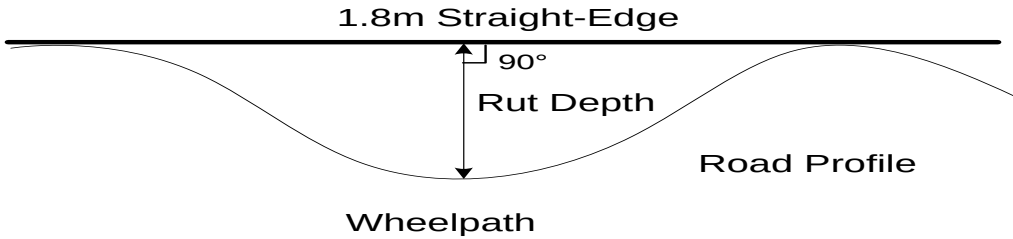
# In-Lab Test – Manual Measurement



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



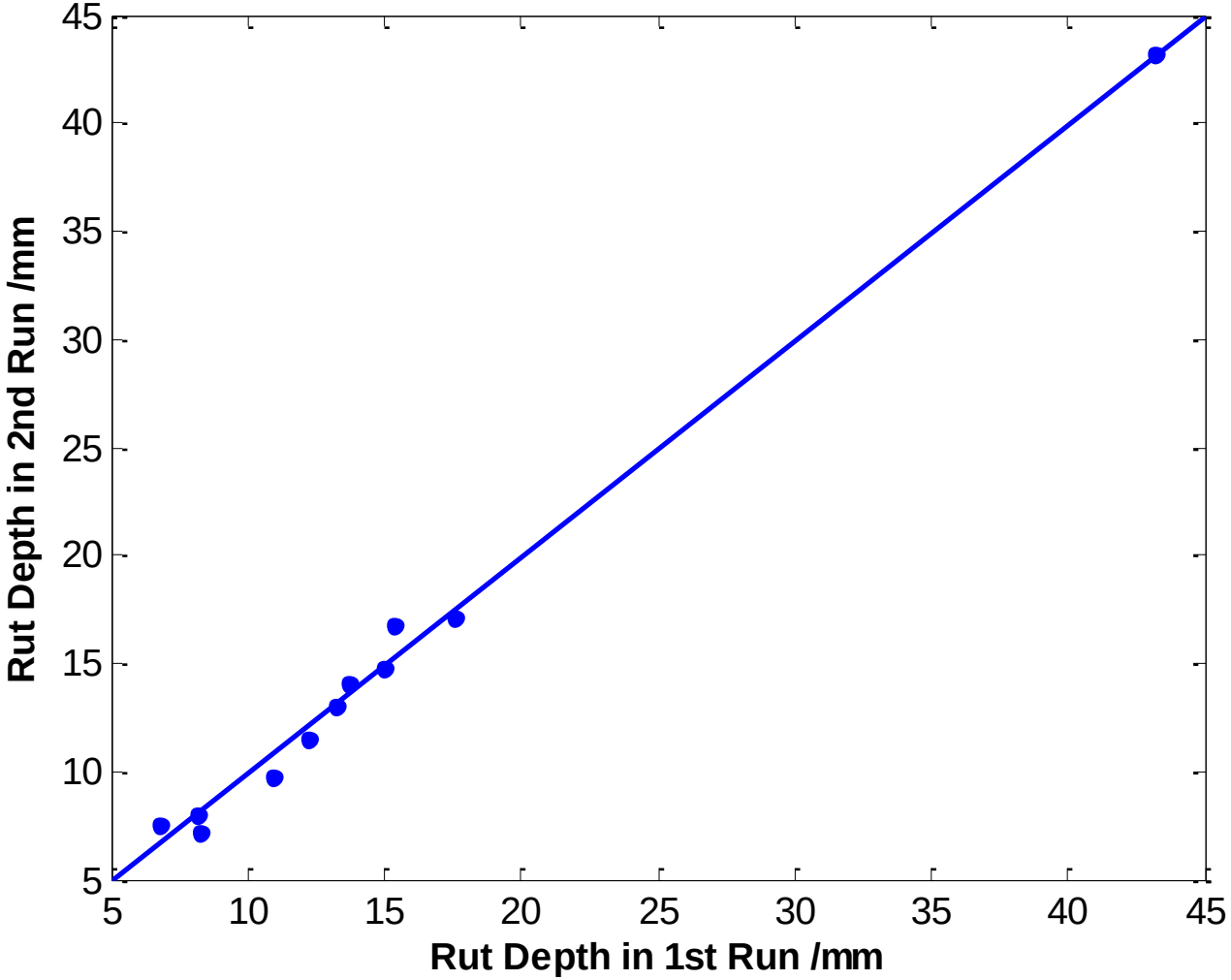

Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

# 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

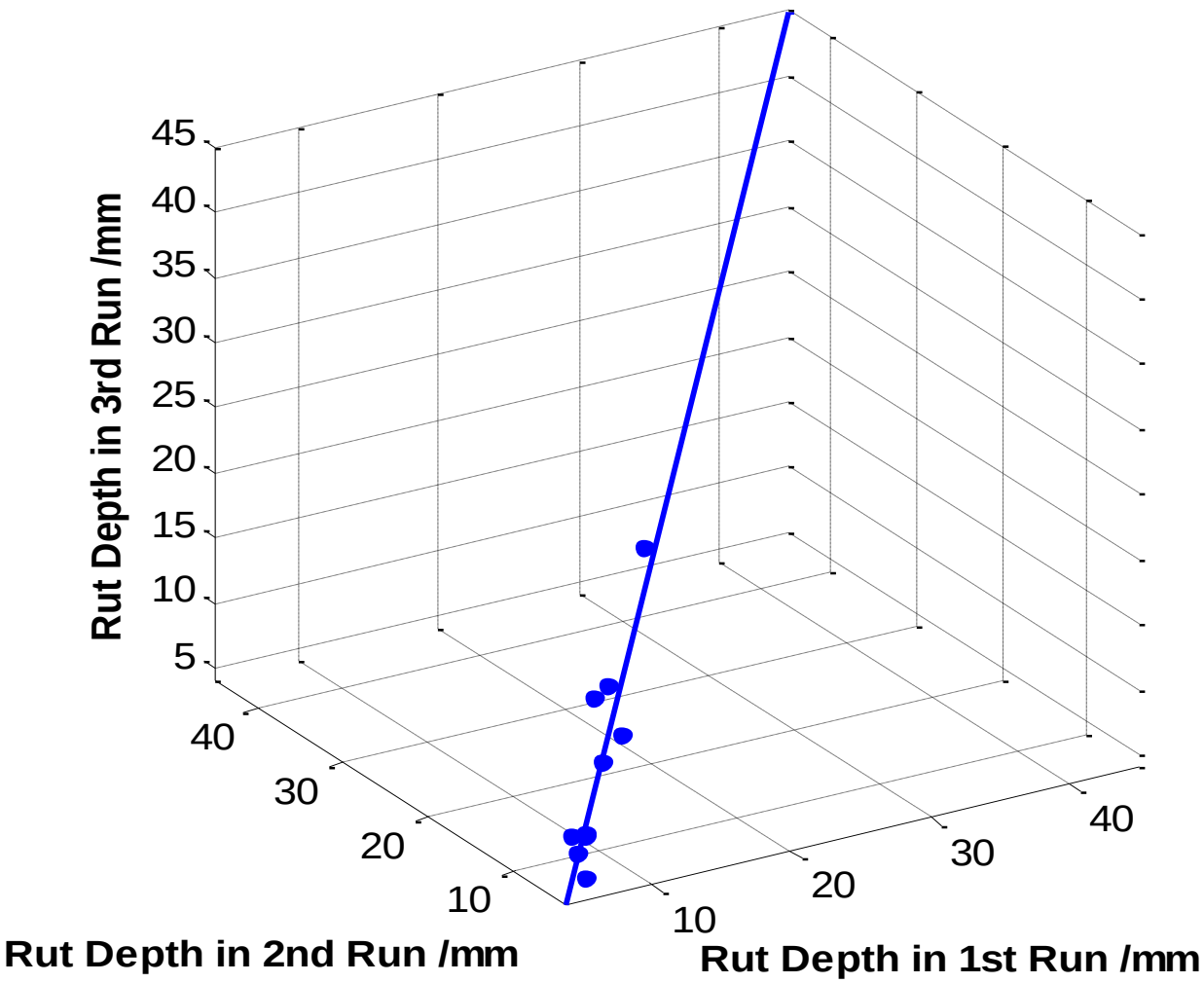
Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

# Field Tests - 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.

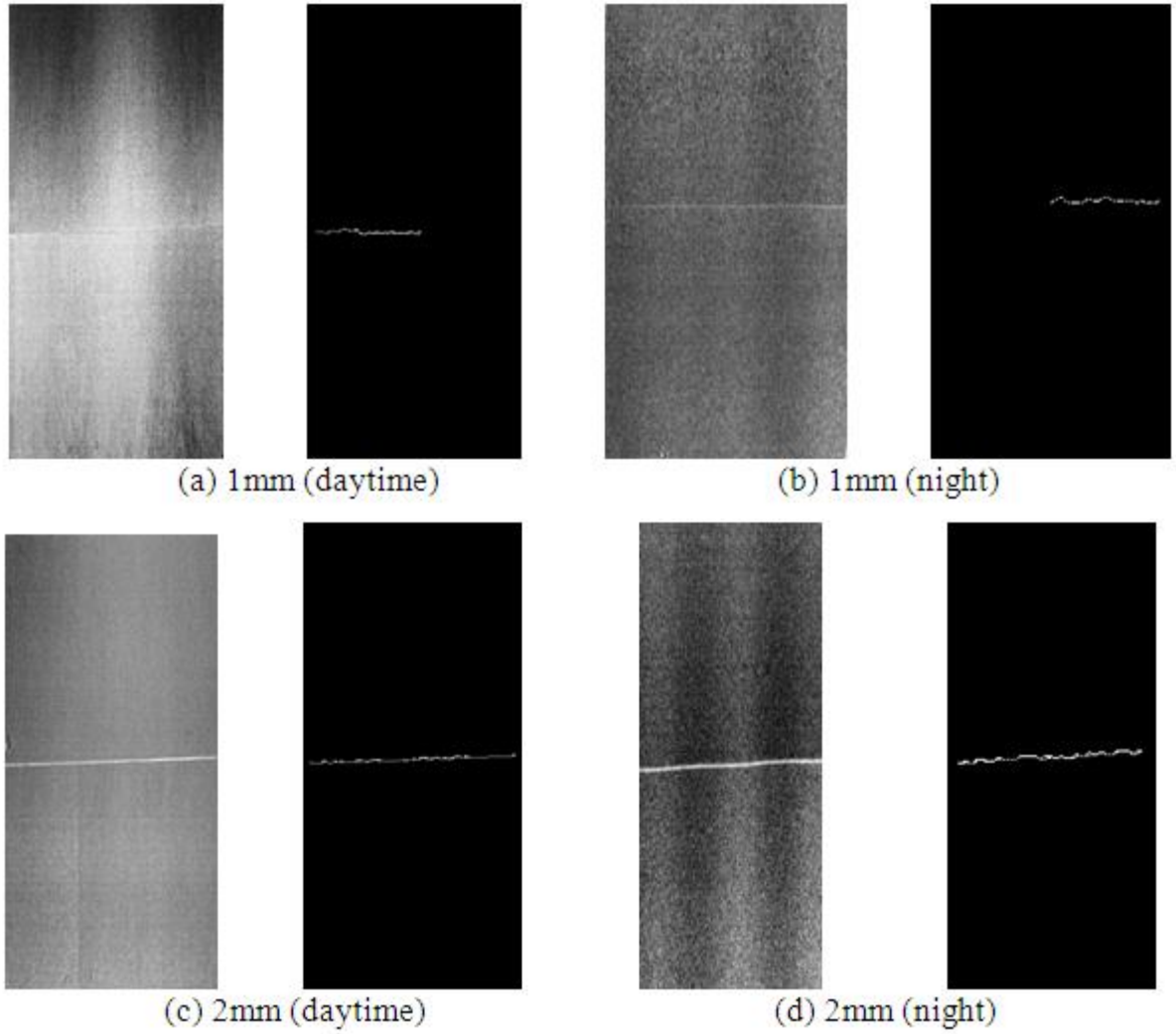
# Field Test - Results (Cont'd)




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)

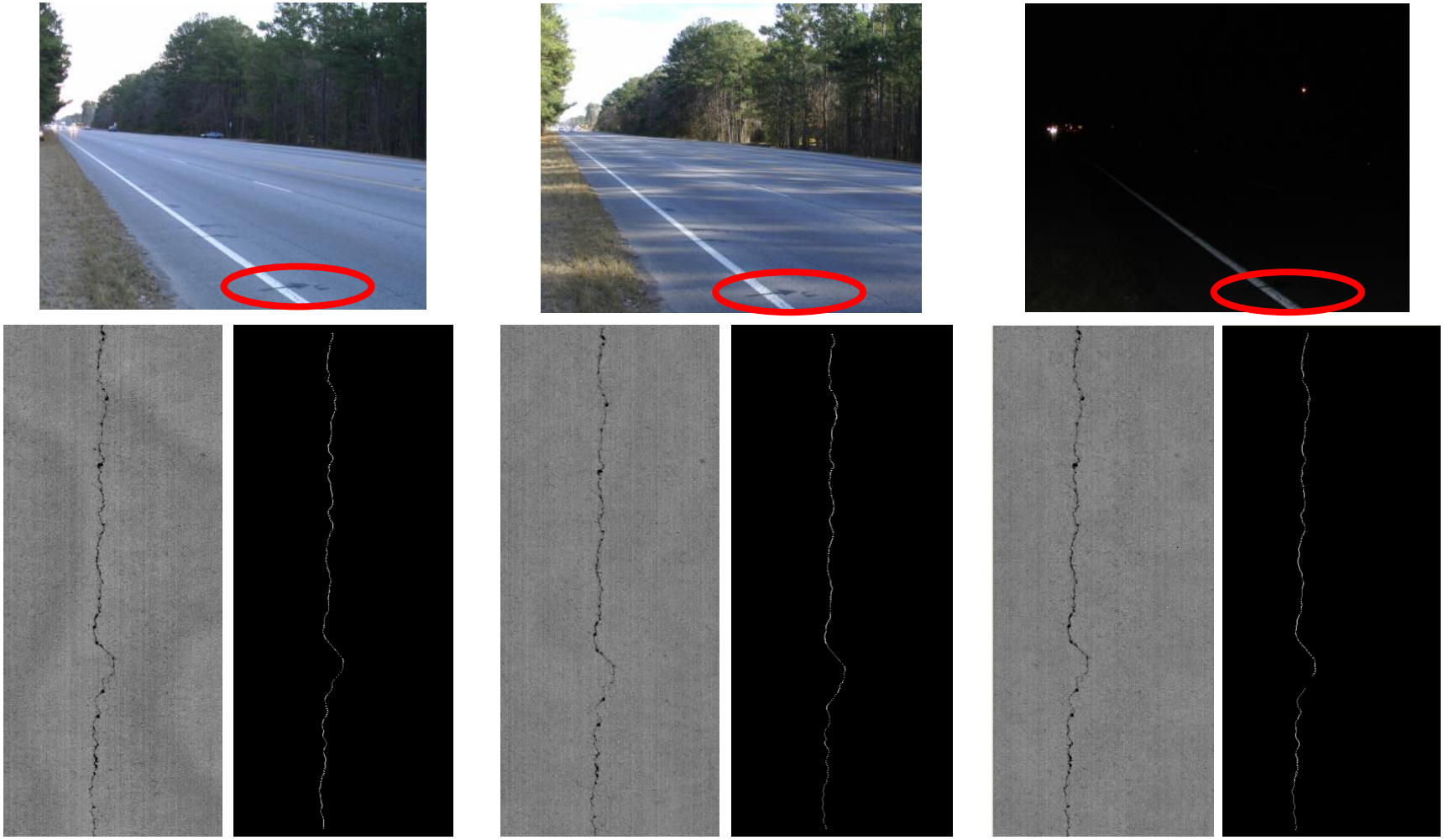
(b) 1mm (night)

(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.

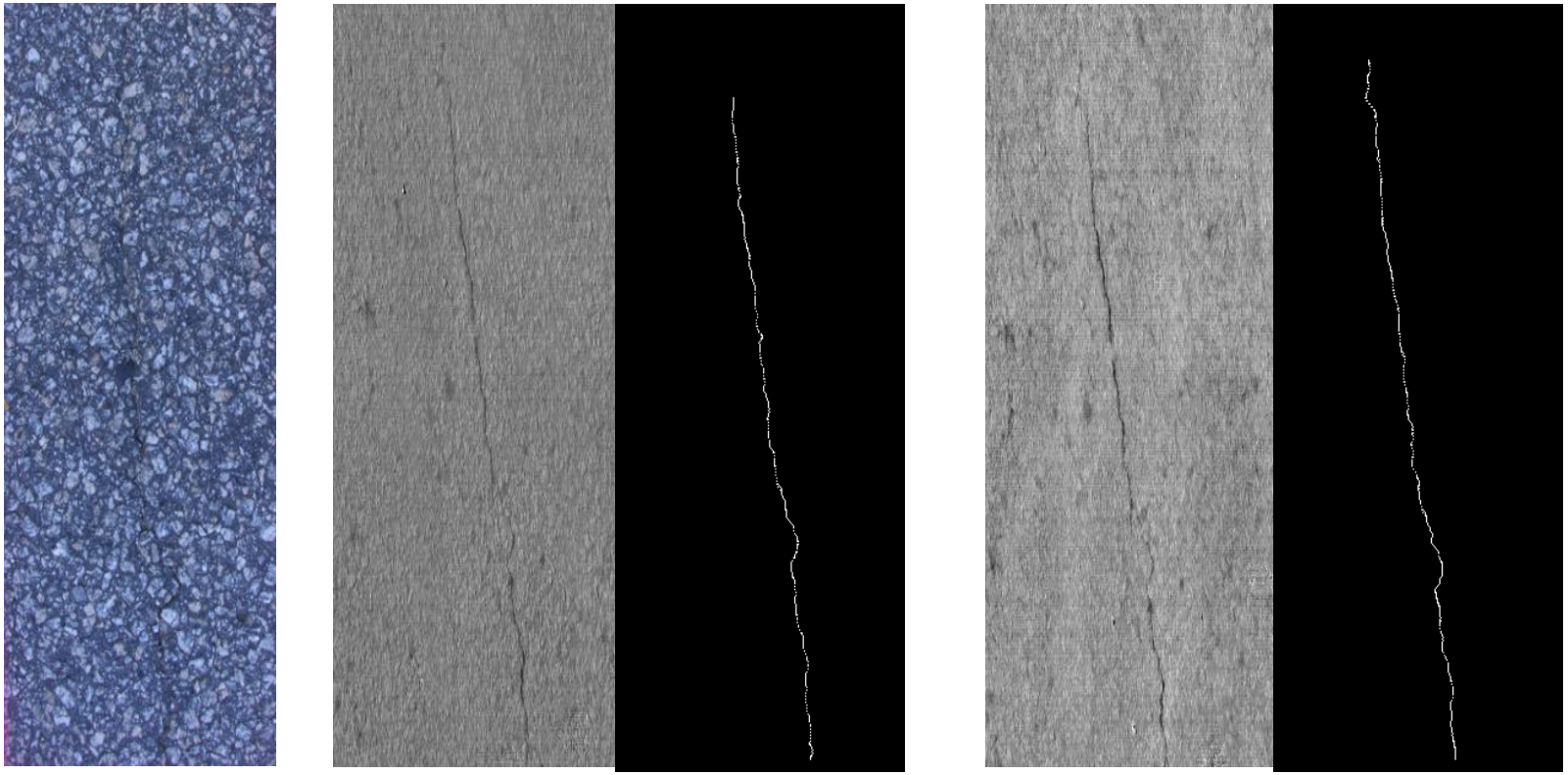
# Field Test #1 - Different Lighting Conditions



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

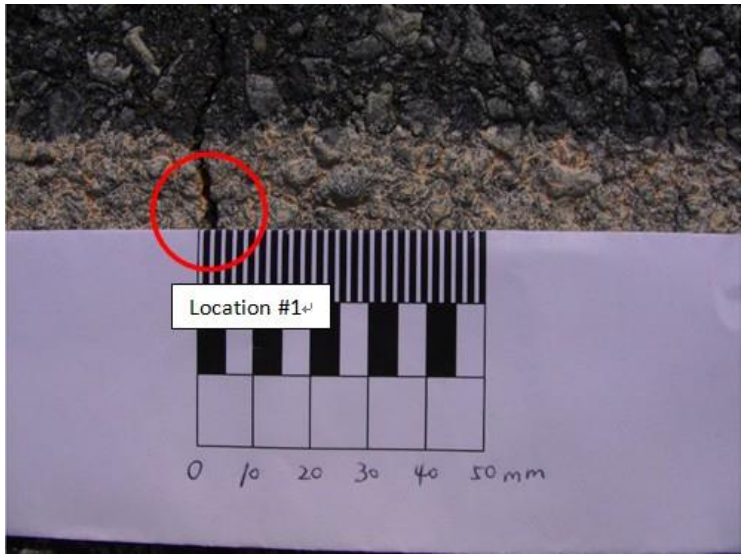


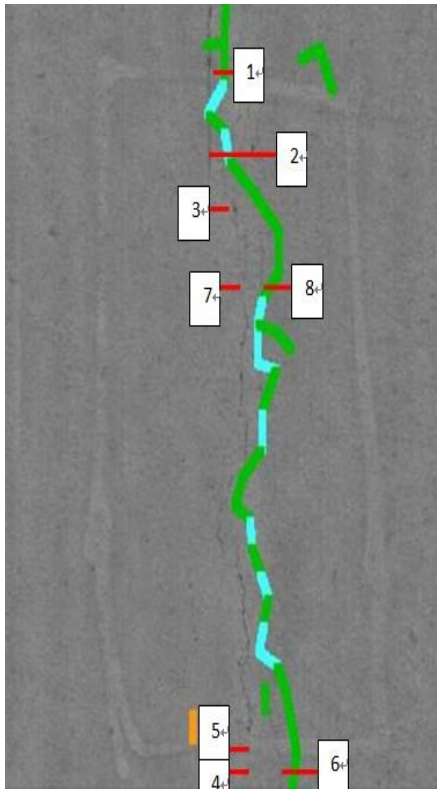
**Daytime (score = 98.3)** **Night (score = 98.0)**

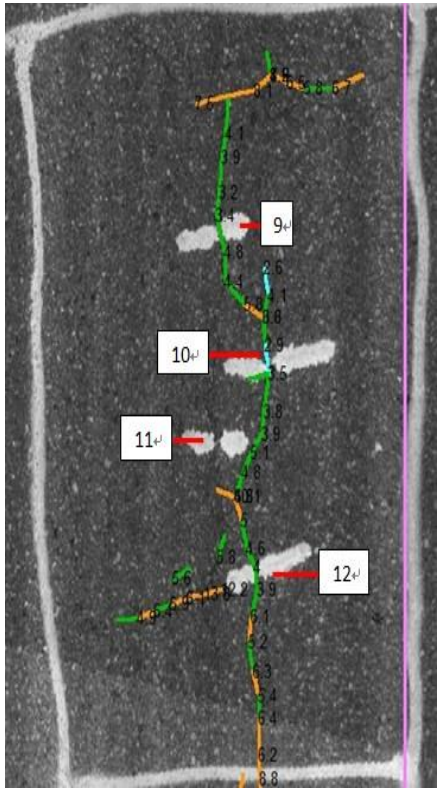
Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

# Crack Width Measurement

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

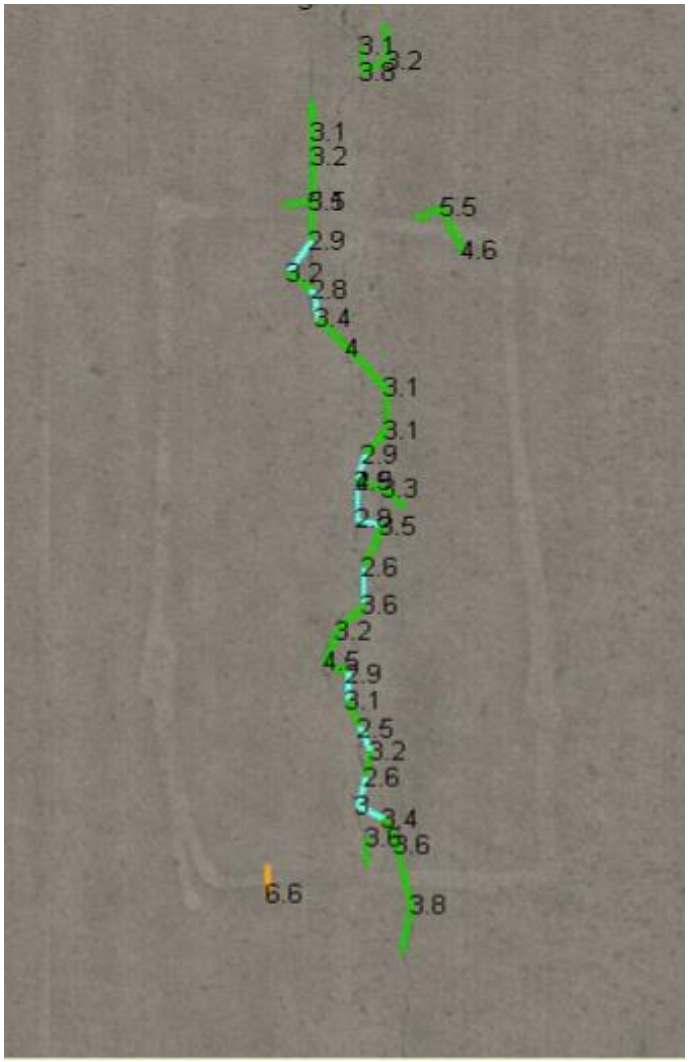


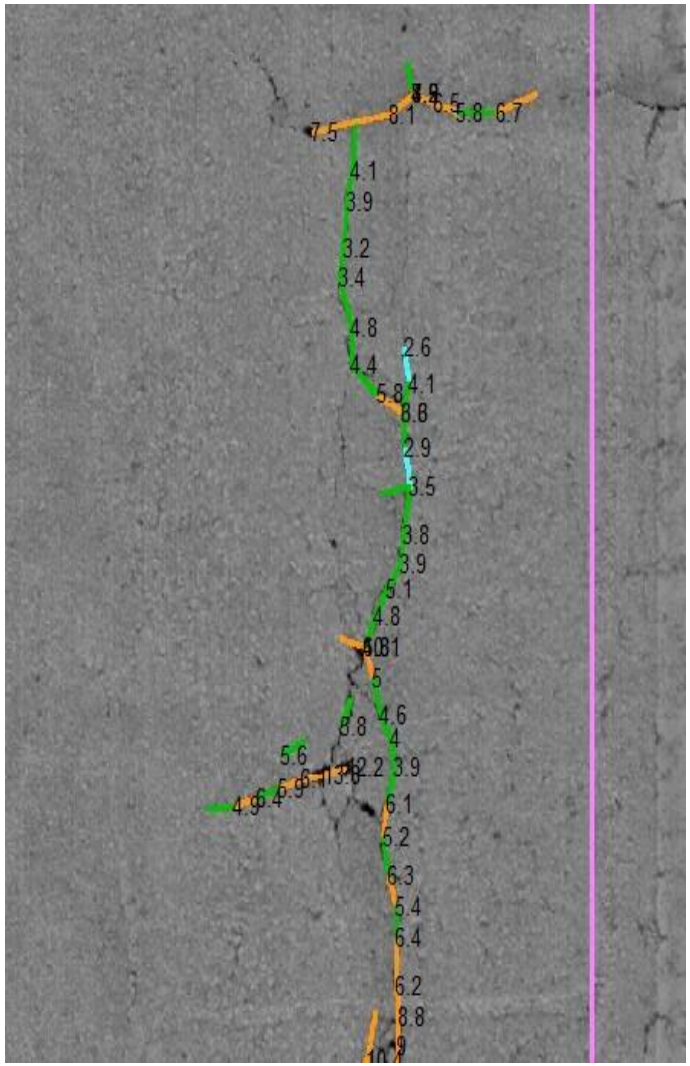




Tsai, Y. C. and Wang, Z. (2013). "A Remote Sensing and GIS-Enabled Asset Management System (RS-GAMS)." Final Report for USDOT project: DTOS59-10-H-0003.

# Crack 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.

# Transverse Profile Measurement Accuracy

John B. Ferris, Director of VTPL

June 2, 2015

# Outline

Motivation for Accurate Surface Measurements

Transverse Profile Measurement Accuracy

- Data Acquisition
- Data Analysis

Conclusions

# Motivation for Accurate Surface Measurements

## Background on Existing Systems and Techniques

- Courtesy of James Tsai…
  - Existing Measurement Systems
  - Possible Sources of Error
  - Definitions of Calibration and Validation
  - Various Calibration Surfaces in Use
  - "It is suggested to use a standardized validation board to directly validate range measurement accuracy following a standard procedure"
    - Thank you, Yichang (James) Tsai!

# Motivation for Accurate Surface Measurements

"Garbage in, garbage out"

- If we want to
  ***assess pavement surface distresses***
  then we must begin with
  ***accurate pavement surface measurements***

Not just, "Is the system acceptable"?

- But also, "How accurate is this system?"
- Makes possible an informed, quantitative,
  ***cost/benefit analysis***

# Motivation for Accurate Surface Measurements

## Need to know the sub-system accuracy

- Identify the area(s) where the errors are hiding
- Makes possible an informed, quantitative, ***quality improvement plan***
- Calibrate our equipment and validate our processing and ***improve our systems***

## We are not alone…

- This is an issue for a many communities

# Motivation for Accurate Surface Measurements

## Sponsors

NSF

U.S. Department of Transportation
Federal Highway Administration

NASA

CHRYSLER

JOHN DEERE

INO

Excellence In Testing
ATC
Aberdeen Test Center

NAC
NATIONAL AUTOMOTIVE CENTER

TARDEC

# Motivation for Accurate Surface Measurements

A loaded question, *"How accurate is this system?"*

Key elements to answer

- Is the test data useful?
  - What does data demonstrate about the system/components?
- Under what test condition(s)?
  - Each test is necessary, but not sufficient
  - More tests provide a more robust assessment
- How should the statement of accuracy be formulated?
  - Traceable to ground truth
  - Statistically sound, but understandable

# Motivation for Accurate Surface Measurements

Quality Improvement in Data Acquisition

1993 – 2001
Chrysler

2001 - 2005
ZF Lemförder

2006 Vehicle Terrain Performance Lab

2008 TARDEC Profilometer

2011 Aberdeen Test Center Profilometer

# Motivation for Accurate Surface Measurements

## Data Acquisition Examples from RPUG Demonstration

- Some *examples* (not all of the tests are presented here)
- Traceable to ground truth
- Test condition(s)
- Usefulness of the data

# Data Acquisition

## Ground Truth

- Flat beam

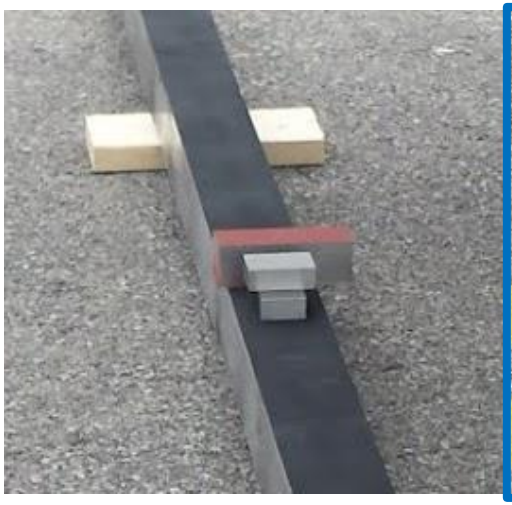
## Test Conditions

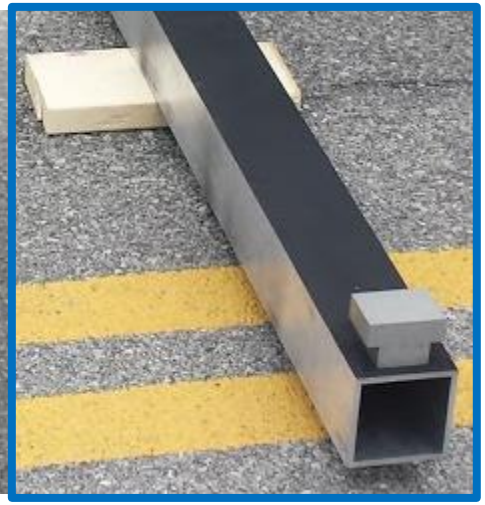
- Static testing
- Various surface finishes

## Usefulness

- Ability to establish a flat datum line, (from which rutting can be established) under various surface conditions

# Data Acquisition





## Ground Truth

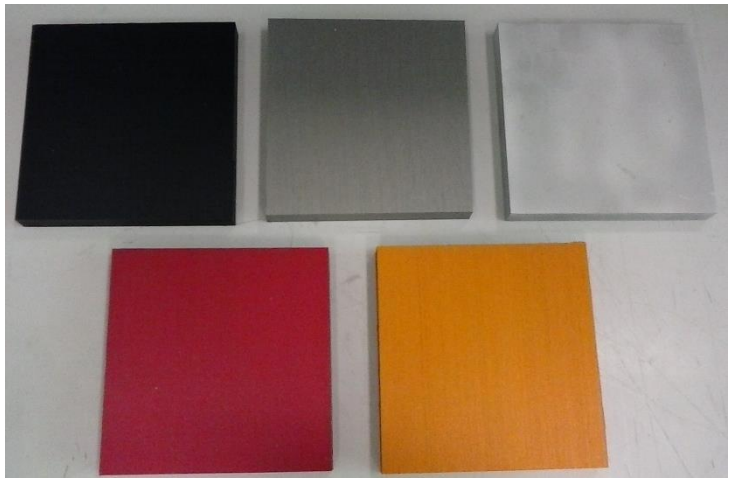
- Flat beam
- Gauge blocks

## Test Conditions

- Static testing
- Various surface finishes

## Usefulness

- Ability to accurately measure changes in height at various lateral locations



# Data Acquisition

## Ground Truth

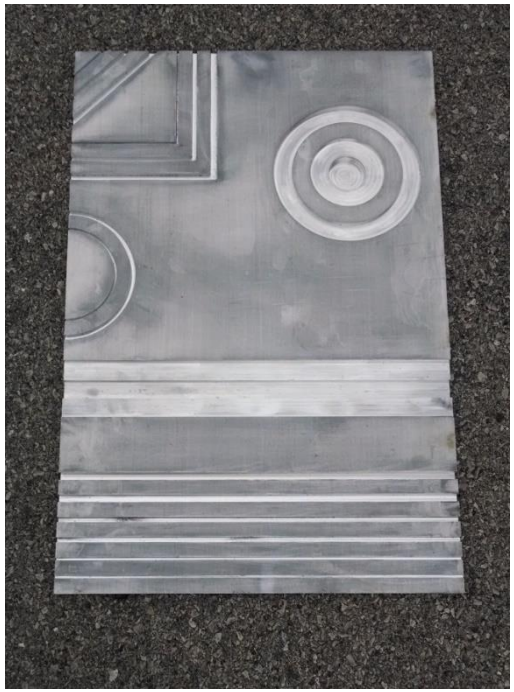
- Calibration surface

## Test Conditions

- Driving test
- No excitation

## Usefulness

- Ability to accurately measure surface when vehicle is not excited



# Data Acquisition

## Ground Truth

- Station Marker

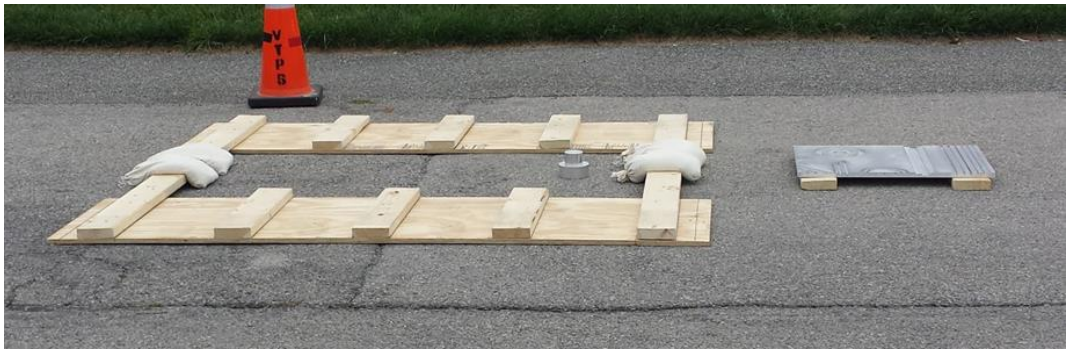
## Test Conditions

- Driving test
- No excitation
- Figure-8
- Several minutes

## Usefulness

- Ability to accurately measure horizontal location without drift

# Data Acquisition




## Ground Truth

- Station Marker
- Calibration Plate

## Test Conditions

- Driving test
- With excitation

## Usefulness

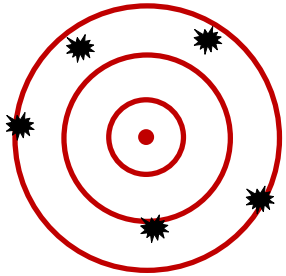
- Ability to accurately measure surface while canceling vehicle body motion

# Data Analysis

## Terminology (Some of which seems inappropriate to me…)

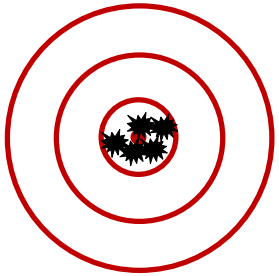
Term: “Precise”
Statistic:
standard deviation

(to me, this is ‘bad’,
it clearly has errors)



Term: “Accurate”
Statistic:
mean

(to me, this is also ‘bad’,
it clearly has errors,
perhaps ‘unbiased’ ?)



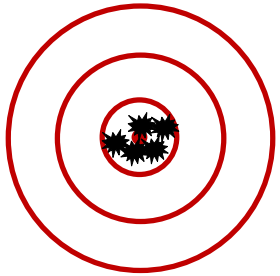
***Define a measure that captures errors in both the mean and standard deviation***

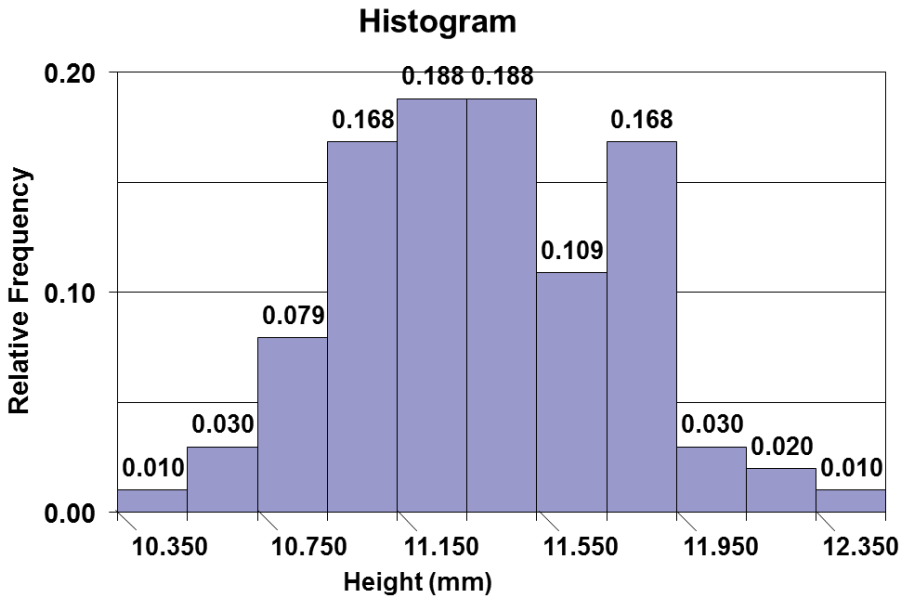
***Consider the 90% confidence interval***

# Data Analysis

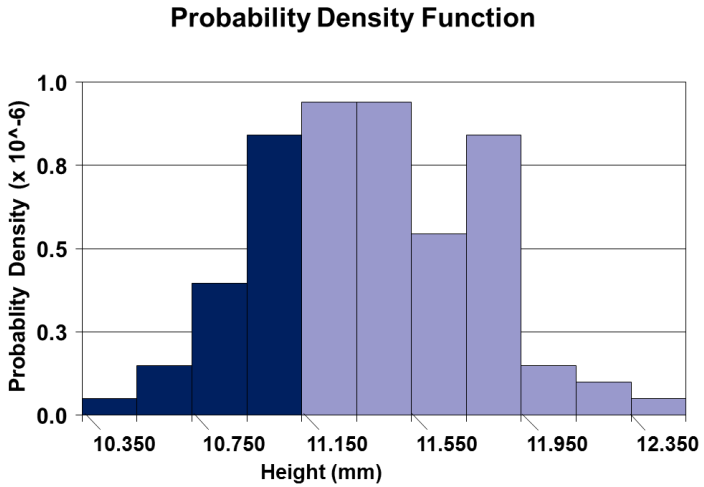
How best to quantify error or “accuracy”?

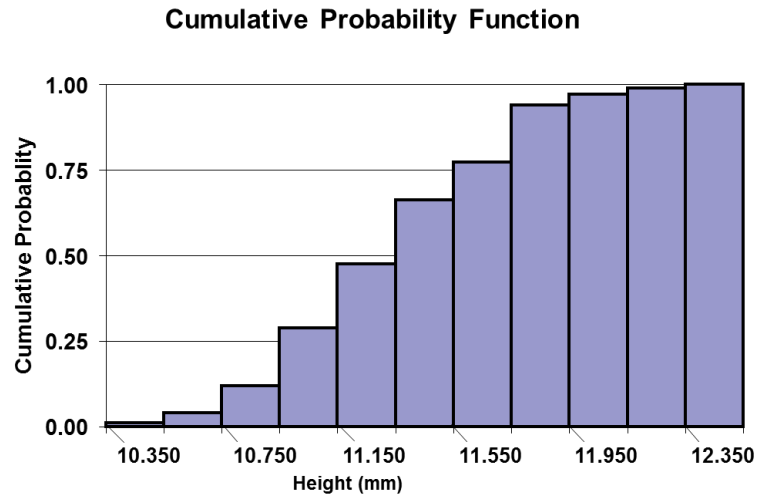
Consider some height measurements

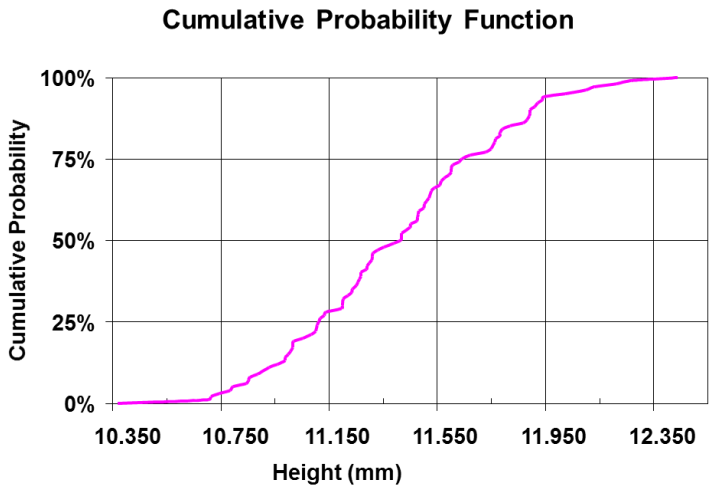




# Vehicle Terrain Performance Laboratory (VTPL)

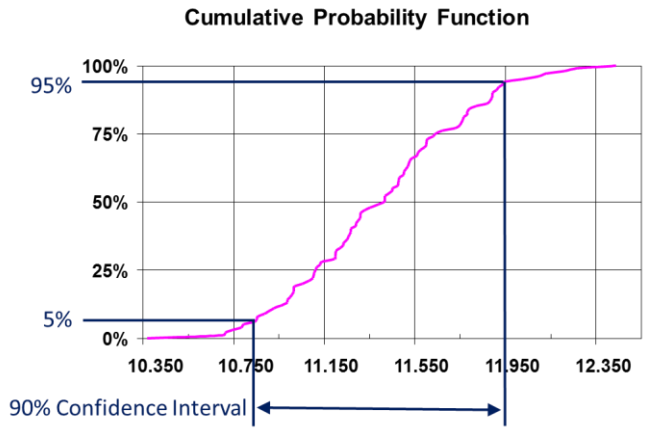



No need to ‘bin’ the data

# Data Analysis

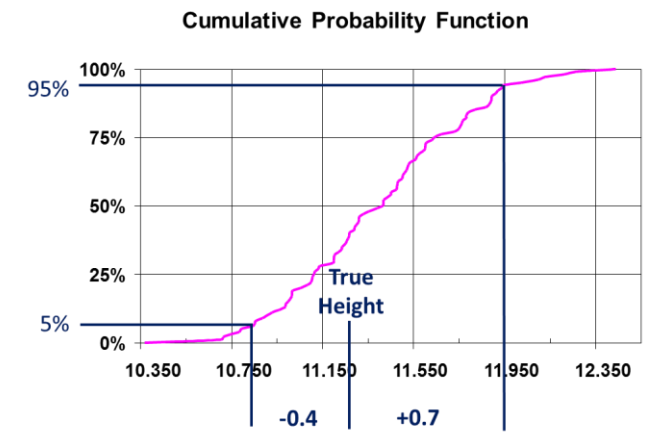



So the 90% confidence interval for the height is

11.950 – 10.850 = 1.10 mm

What if the *true* height is

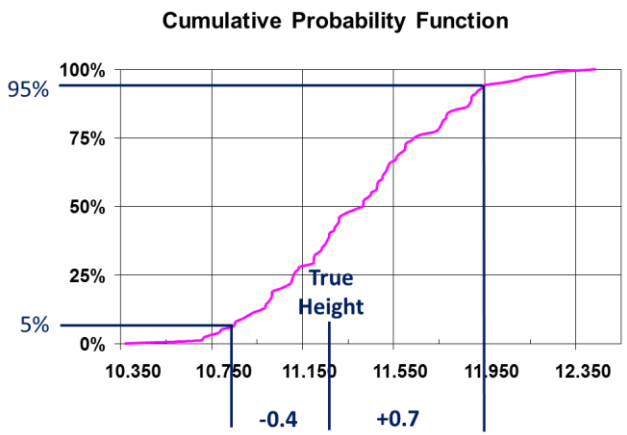
11.250 mm?



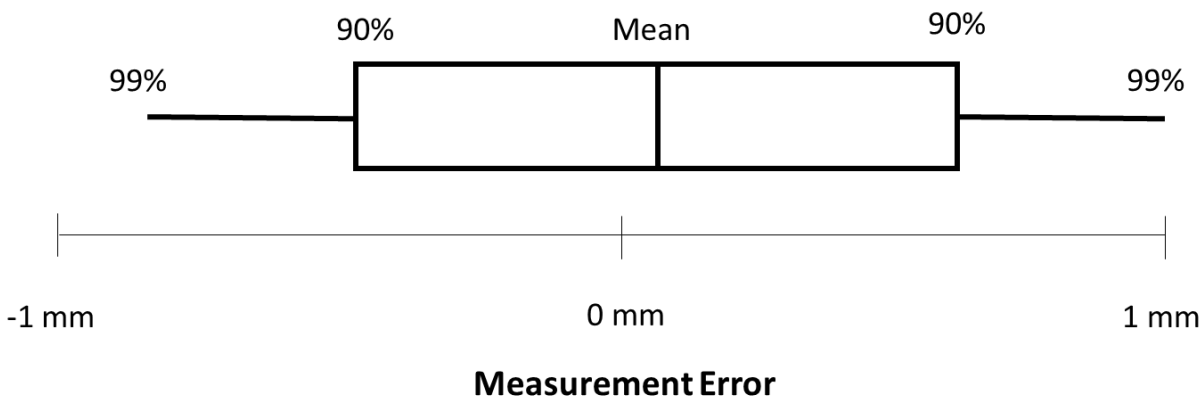

Then the 90% confidence for the error is

-0.4 mm to 0.7 mm

# Data Analysis



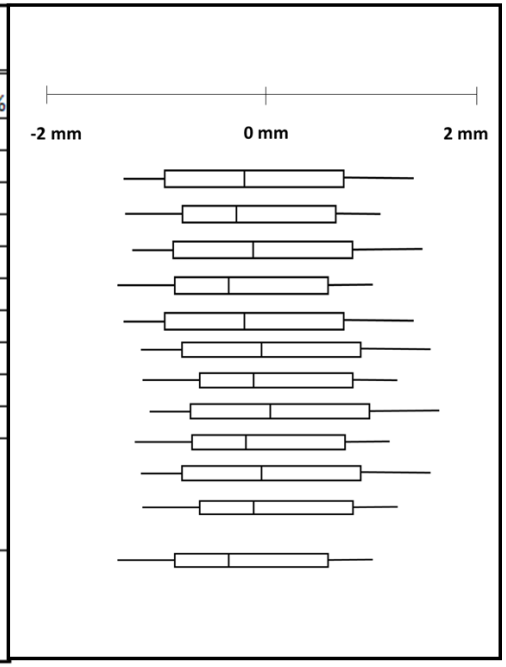

A convenient way to represent this is a box plot



# Data Analysis

Entire set of *test results* and *specifications* could be written something like…

| Event | | Lower Bound | | Upper Bound | |
|---|---|---|---|---|---|
| **Confidence Used** | | 50% | 90% | 50% | 90% |
| Straight Edge Test - For various heights from base measurement height | -25.4 mm | | | | |
| | -12.7 mm | | | | |
| | 0 mm | | | | |
| | 12.4 mm | | | | |
| | 25.4 mm | | | | |
| Guage Block Test - For various heights from base measurement height | -25.4 mm | | | | |
| | -12.7 mm | | | | |
| | 0 mm | | | | |
| | 12.4 mm | | | | |
| | 25.4 mm | | | | |
| GPS Drift Test | | | | | |
| Crack Detection Test | | | | | |



# Conclusions

First steps toward

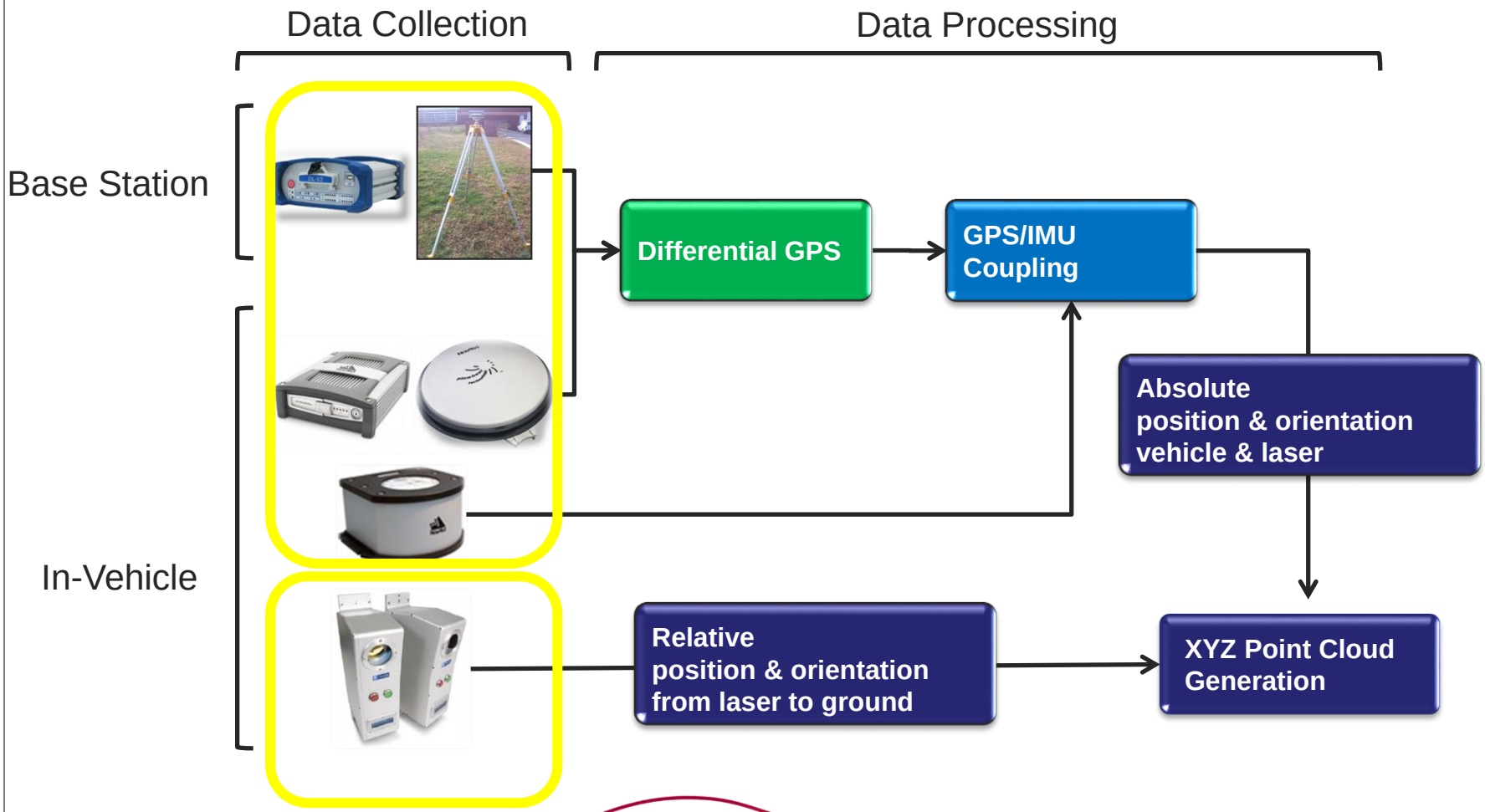
- Answering the question, “How accurate is this system?”
  - Traceable to ground truth
  - Statistically sound, but understandable
- Developing a process for informed, quantitative decisions
  - Cost/benefit analyses
  - Quality improvement plans

Questions?

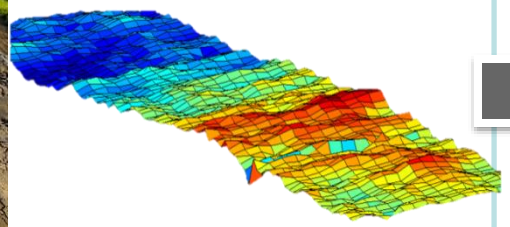
Thank you!

# Backup Slides

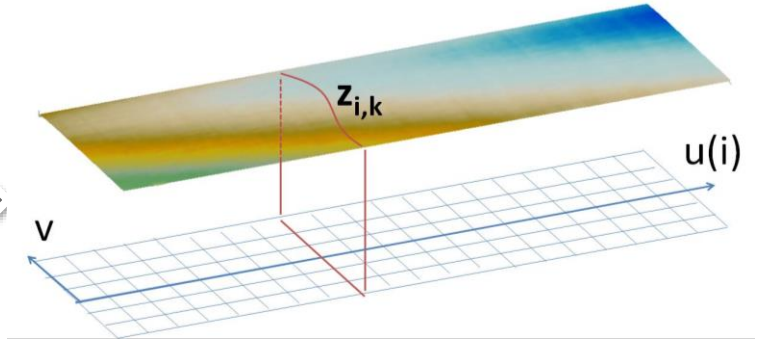
# Terrain Surface Measurement



# Motivation for Accurate Surface Measurements



**Terrain Measurement**




**Terrain Modeling**

**Vehicle Modeling**

**Analysis and Prediction**

- **Virtual Proving Grounds**
- **Driver Assistance Systems**
- **Automated Vehicles**

# Sample of Relevant Journal Publications

Chung*, H., North, C., Ferris, J.B., 2013. "Developing Large High-Resolution Display Visualizations of High-Fidelity Terrain Data." J. Comput. Inf. Sci. Eng. 13(3) :034502-034502-7, ASME, 7 pages. doi:10.1115/1.4024656

Chemistruck*, H. M., Ferris, J.B., 2013. “Developing Compact Models of Terrain Surfaces.” Journal of Dynamic Systems Measurement and Control, Vol. 135, No. 6, 061008 (Aug 23, 2013)9 pages. doi:10.1115/1.4025016.

Ma*, R., Chemistruck*, H. M., Ferris, J.B., 2013. “State-of-the-art of Terrain Characterization Models.” International Journal of Vehicle Design, Special Issue on Modeling and Simulation of Ground Vehicle Systems, Guest Editors Zoran Filipi and David Gorsich, pp 285-304, Vol. 61, No. 1/2/3/4, 2013, pg 285-304 doi:10.1504/IJVD.2013.050850.

Wagner*, S. M. and Ferris, J. B., 2012, “Residual Analysis of Autoregressive Models of Terrain Topology,” Journal of Dynamic Systems Measurement and Control, Volume 134, Issue 3, 031003 (6 pages) doi: 10.1115/1.4005502.

Wagner*, S. M. and Ferris, J.B., 2012, “Developing compact autoregressive characterisations of terrain topology profiles”, Int. J. Vehicle Systems Modelling and Testing, Vol. 7, No. 1, pp.12–25. (DOI: 10.1504/IJVSMT.2012.045312)

# Sample of Relevant Journal Publications

Chemistruck*, H. M., Ferris, J.B., Gorsich, D., 2012. “Using a Galerkin Approach to Define Terrain Surfaces.” Journal of Dynamic Systems Measurement and Control, Volume 134, Issue 2, 021017 (12 pages) dui: 10.1115/1.4005271

Wagner*, S. M. and Ferris, J. B., 2011, “Stability and Interpretation of Autoregressive Models of Terrain Topology,” Journal of Dynamic Systems Measurement and Control. Vol. 133, No. 2, Article 021003 (2011); doi: 10.1115/1.4003092 (5 pages)

Chemistruck*, H. M., Binns*, R., Ferris, J.B., 2010, “Correcting INS Drift in Terrain Surface Measurements” Journal of Dynamic Systems Measurement and Control. Vol. 133, No. 2, Article Number: 021009 (DOI:10.1115/1.4003098).

Smith*, H. and Ferris, J. B., 2010, “Calibration Surface Design and Validation for Terrain Measurement Systems,” Journal of Testing and Evaluation, Vol. 38, No. 4, pp. 431-438.

Smith*, H., Ferris, J.B., 2010, “Techniques for Averting and Correcting Inertial Errors in High-Fidelity Terrain Topology Measurements.” Journal of Terramechanics, Vol. 47, No. 4, pp. 219-225. DOI: 10.1016/j.jterra.2010.04.002

Detweiler*, Z. R., and Ferris, J. B., 2010, “Interpolation Methods for High-Fidelity Three Dimensional Terrain Surfaces,” Journal of Terramechanics, Vol. 47, No. 4, pp. 209-217. DOI: 10.1016/j.jterra.2010.01.002

# Sample of Relevant Journal Publications

Wagner*, S. M. and Ferris, J. B., 2009, “Developing Stable Autoregressive Models of Terrain Topology,” International Journal of Vehicle Systems Modelling and Testing, Vol. 4, No. 4, pp. 306-317.

Ferris, J. B., 2004, "Characterizing Road Profiles as Markov Chains," International Journal of Vehicle Design, Special Edition on Road Profiles: Measurement, Analysis, and Applications, Vol. 36, No. 2/3, pp. 103-115. DOI: 10.1504/IJVD.2004.005351

Saeger**, K. M., and Ferris, J. B., 2003, "Plausibility Checking of Road Profile Measurements," SAE 2003 Transactions – Journal of Passenger Cars: Electronic and Electrical Systems, paper 2003-01-0669, SAE, Detroit, MI.

Ferris, J. B., and Larsen, J. L., 2002, "Establishing Chassis Reliability Testing Targets Based on Road Roughness," International Journal of Materials & Product Technology, Vol. 17, No. 5/6, pp. 453-461. DOI: 10.1504/IJMPT.2002.005470

# Sample of Relevant Conference Publications

Deasy*, C.M., Ferris, J.B., Tjhung, T., and Horn, E., 2014, "A Nodal Uncertainty Method to Detect Localized Events from Measured Terrain Surfaces," Proceedings of the ASME Dynamic Systems and Control Conference (DSCC2014), Paper Number DSCC2014-6242, October 22-24, San Antonio, TX, USA.

Lambeth*, J. N., Ferris, J.B., Reid , A., Gorsich, D., 2012. "Developing a Compact Continuous State Markov Chain for Terrain Road Profiles." Proceedings of the SAE World Congress and Exhibition, April 16-18, Cobo Center, Detroit, Michigan, Paper Number 2013-01-0629. doi:10.4271/2013-01-0629

Chin*, P.A., Ferris, J.B., 2012, " Methodology for Optimizing First Order Markov Chains of Spectrally Decomposed Terrain Profiles," Proceedings of the ASME Dynamic Systems and Control Conference (DSCC), Vol. 3, pg 299-307, Paper Number 8746, October 17-19, Fort Lauderdale, FL.

Chin*, P.A., Ferris, J.B., 2012, "Improving Markov Chain Models for Road Profiles Simulation via Definition of States," Proceedings of the ASME/IEEE American Control Conference, Paper Number 2080, 2012 American Control Conference (ACC), pg 2102-2107, Fairmont Queen Elizabeth, Montréal, Canada on June 27-June 29, 2012.

Ma*, R., Ferris, J.B., 2011, "Terrain Gridding Using a Stochastic Weighting Function," Proceedings of the ASME Dynamic Systems and Control Conference (DSCC), Vol. 2, pg 375-381, October 31 – November 2, Arlington, Virginia

# Sample of Relevant Conference Publications

Kawale*, S. J., Ferris, J. B., 2011, “Developing a Methodology to Synthesize Terrain Profiles and Evaluate their Statistical Properties,” Proceedings of the SAE World Congress and Exhibition, April 12-14, Cobo Center, Detroit, Michigan, Paper Number 2011-01-0182 (doi:10.4271/2011-01-0182).

Kern*, J.V., Ferris, J.B., 2007, “Development of a 3-D Vehicle-Terrain Measurement System Part I: Equipment Setup,” Proceedings of ISTVS: Innovations in Terrain and Vehicle Systems, ISTVS, Fairbanks, AK.

Wagner*, S.M., Kern*, J.V., Israel*, W.B., Ferris, J.B., 2007, “Development of a 3-D Vehicle-Terrain Measurement System Part II: Signal Processing and Validation,” Proceedings of ISTVS: Innovations in Terrain and Vehicle Systems, ISTVS, Fairbanks, AK.

Wagner*, S. M., and Ferris, J. B., 2007, “Reduced Order ARIMA Models of 2-D Terrain Profiles Using Singular Value Decomposition," Proceedings of the ASME International Congress and Exposition, Vol. 16, pg 277-282, paper number IMECE2007-43388, ASME, Seattle, WA.

Kern*, J. V., and Ferris, J. B., 2006, "Characterizing 2-D Topographic Mappings of Roads," Proceedings of the ASME International Congress and Exposition, paper number IMECE2006-15233, ASME, Chicago, IL.

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# Sample of Relevant Conference Publications

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Gorsich, D. J., Chaika, M., Gunter, D., Karlsen, R., Haueisen, B., Sun, T., Ferris, J. B., 2003, "Terrain Roughness Standards for Mobility and Ultra-Reliability Prediction," Proceedings of the SAE World Congress, SAE, Detroit, MI.

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Ferris, J. B., 2001, "Singular Value Decomposition of Road Events into Characteristic Shapes," Proceedings of the ASME International Congress and Exposition, ASME, New York, NY.

Ferris, J. B., and Larsen, J. L., 2001, "Establishing Chassis Reliability Testing Targets Based on Road Roughness," Proceedings of the Seventh ISSAT International Conference on Reliability and Quality in Design, ISSAT, Washington, D.C., pp. 75-79.

*current or former student

** current or former intern

Road Profiler User Group/Falling Weight Deflectometer User Group, TPF-5(299), and TPF-5(063) workshops and meetings

DRAFT

November 2-6, 2015

**Monday, November 2nd, 2015**

| | |
|---|---|
| 8:00 AM – 5:00 PM | TPF-5(063) Profiler Pooled Fund Study Meeting |
| 1:00 PM – 5:00 PM | FWD User's group workshop |
| 6:00 PM – 8:00 PM | Ice Breaker |

**Tuesday, November 3rd, 2015**

| | |
|---|---|
| 8:00 AM – 12:00 PM | Joined Session FWD/RPUG |
| 12:00-1:00 PM | Lunch |
| 1:00-5:00 PM | RPUG Breakout session |
| 1:00-5:00 PM | FWD Breakout session |

Dinner

**Wednesday, November 4th, 2015**

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|---|---|
| 8:00 AM -5:00 PM | RPUG |

**Thursday, November 5th, 2015**

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|---|---|
| 8:00 AM -5:00 PM | TPF-5(299) Distress Pooled Fund Study Meeting |
| 8:00 AM – 12:00 PM | Proval Workshop |

**Friday, November 6th, 2015**

| | |
|---|---|
| 8:00 AM – 12:00 PM | TPF-5(299) Distress Pooled Fund Study Meeting |