Transverse Profile Measurement Accuracy

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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

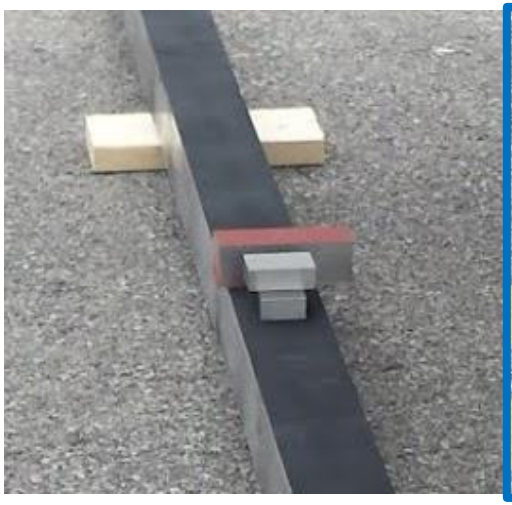
Test Conditions

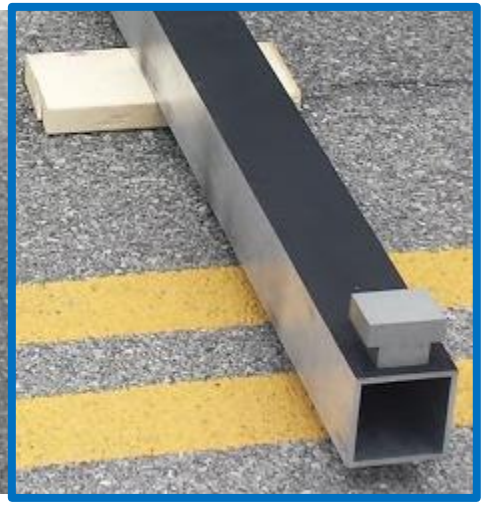
- Static testing
- Various surface finishes

Usefulness

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

Data Acquisition





Ground Truth

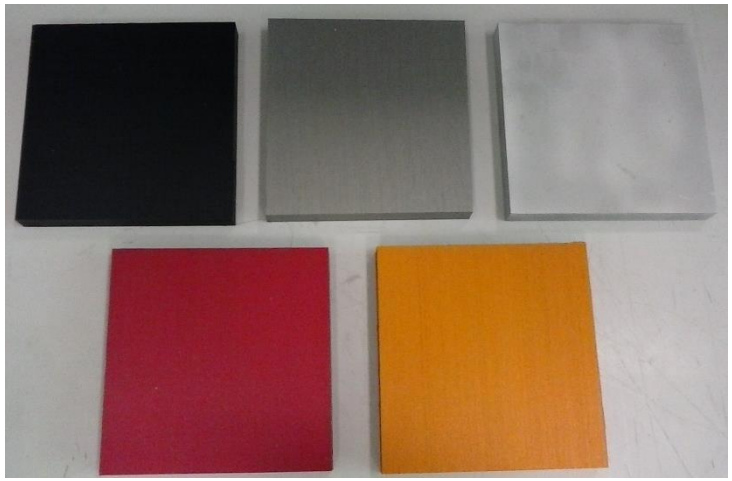
- Flat beam
- Gauge blocks

Test Conditions

- Static testing
- Various surface finishes

Usefulness

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



Data Acquisition

Ground Truth

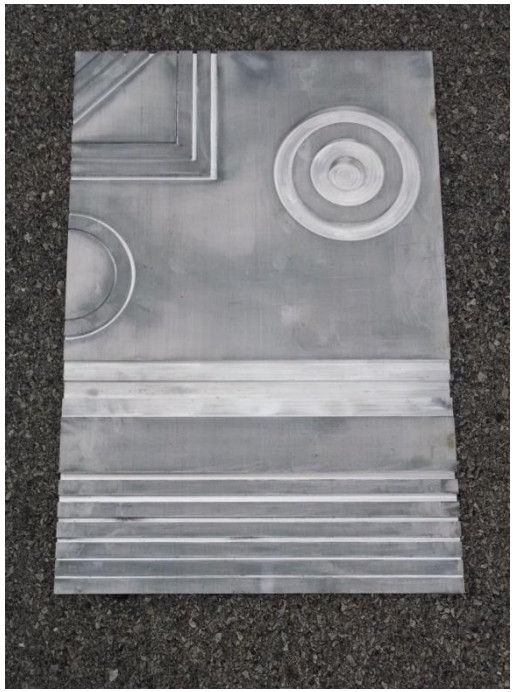
- Calibration surface

Test Conditions

- Driving test
- No excitation

Usefulness

- Ability to accurately measure surface when vehicle is not excited



Data Acquisition

Ground Truth

- Station Marker

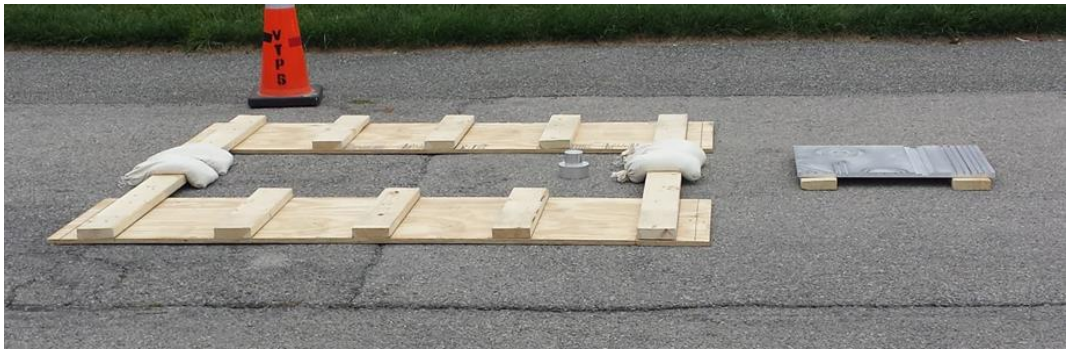
Test Conditions

- 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

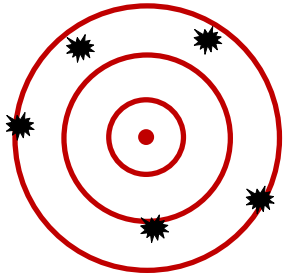
- Ability to accurately measure surface while canceling vehicle body motion

Data Analysis

Terminology (Some of which seems inappropriate to me…)

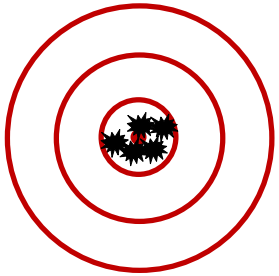
Term: “Precise”
Statistic:
standard deviation

(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’ ?)



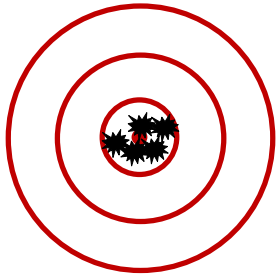
Define a measure that captures errors in both the mean and standard deviation

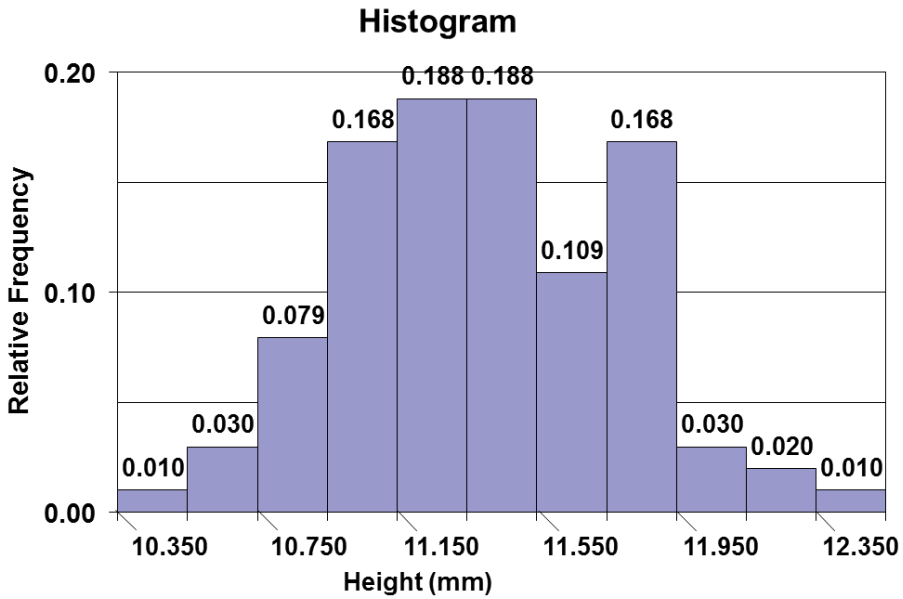
Consider the 90% confidence interval

Data Analysis

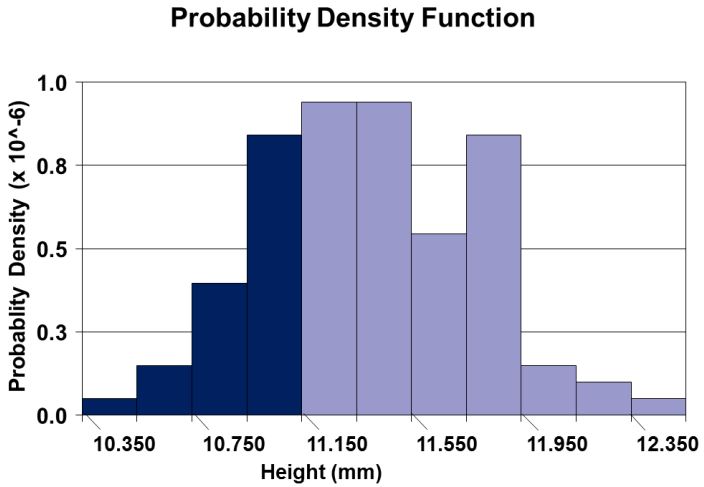
How best to quantify error or “accuracy”?

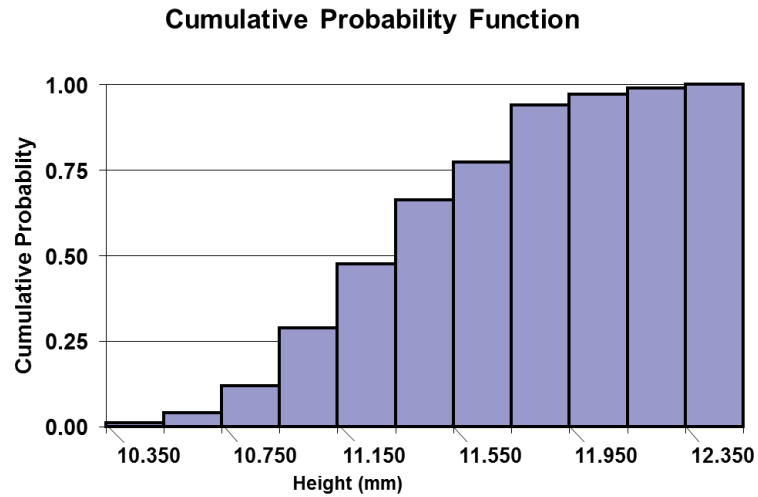
Consider some height measurements

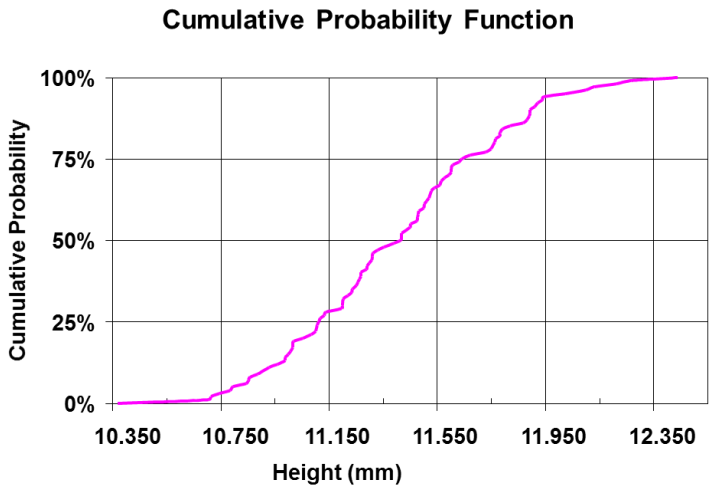




Vehicle Terrain Performance Laboratory (VTPL)

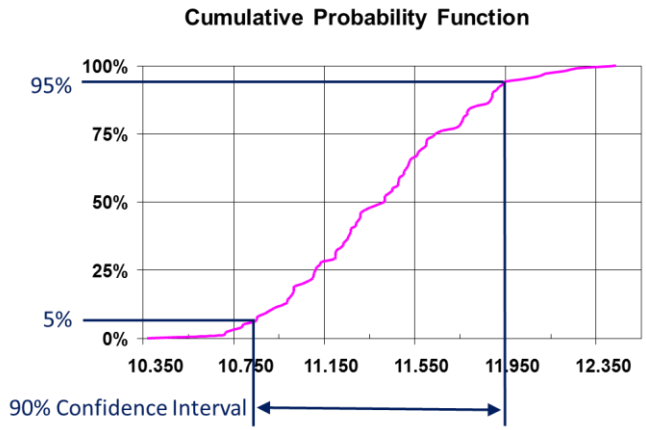






No need to ‘bin’ the data

Data Analysis

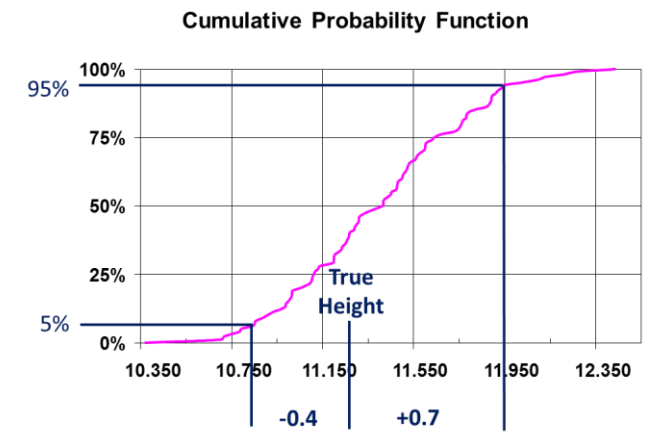


So the 90% confidence interval for the height is

11.950 – 10.850 = 1.10 mm

What if the *true* height is

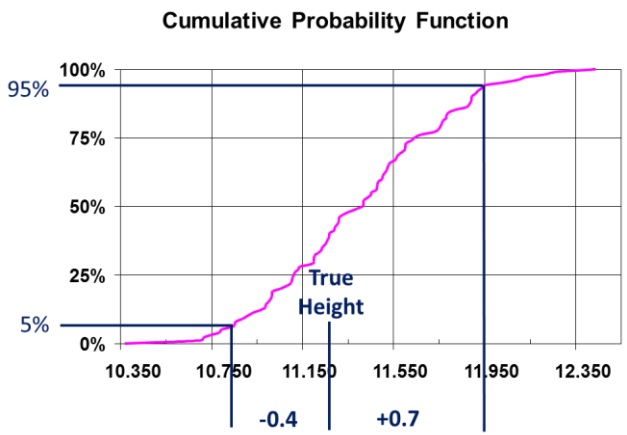
11.250 mm?



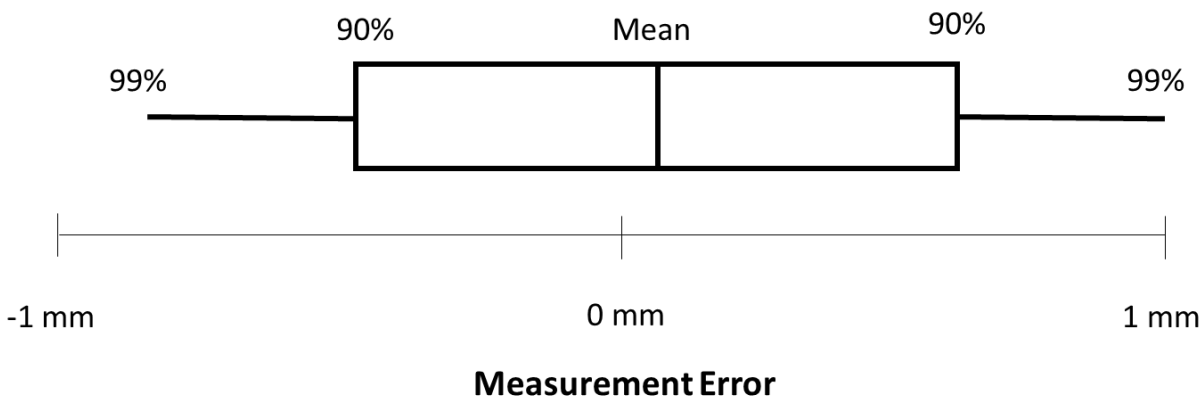
Then the 90% confidence for the error is

-0.4 mm to 0.7 mm

Data Analysis



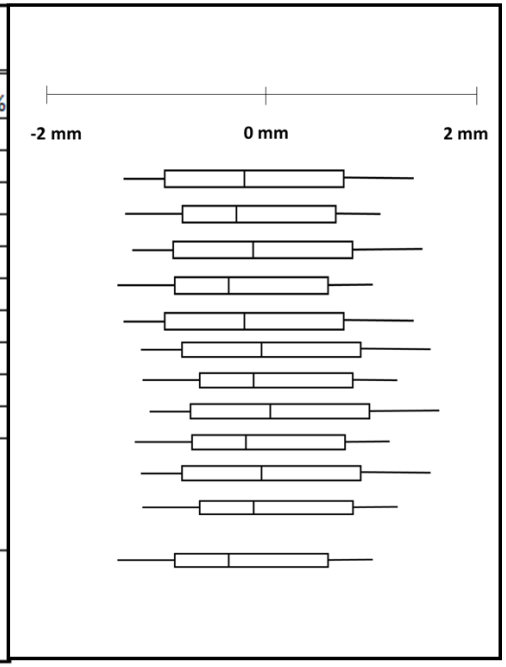
A convenient way to represent this is a box plot



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

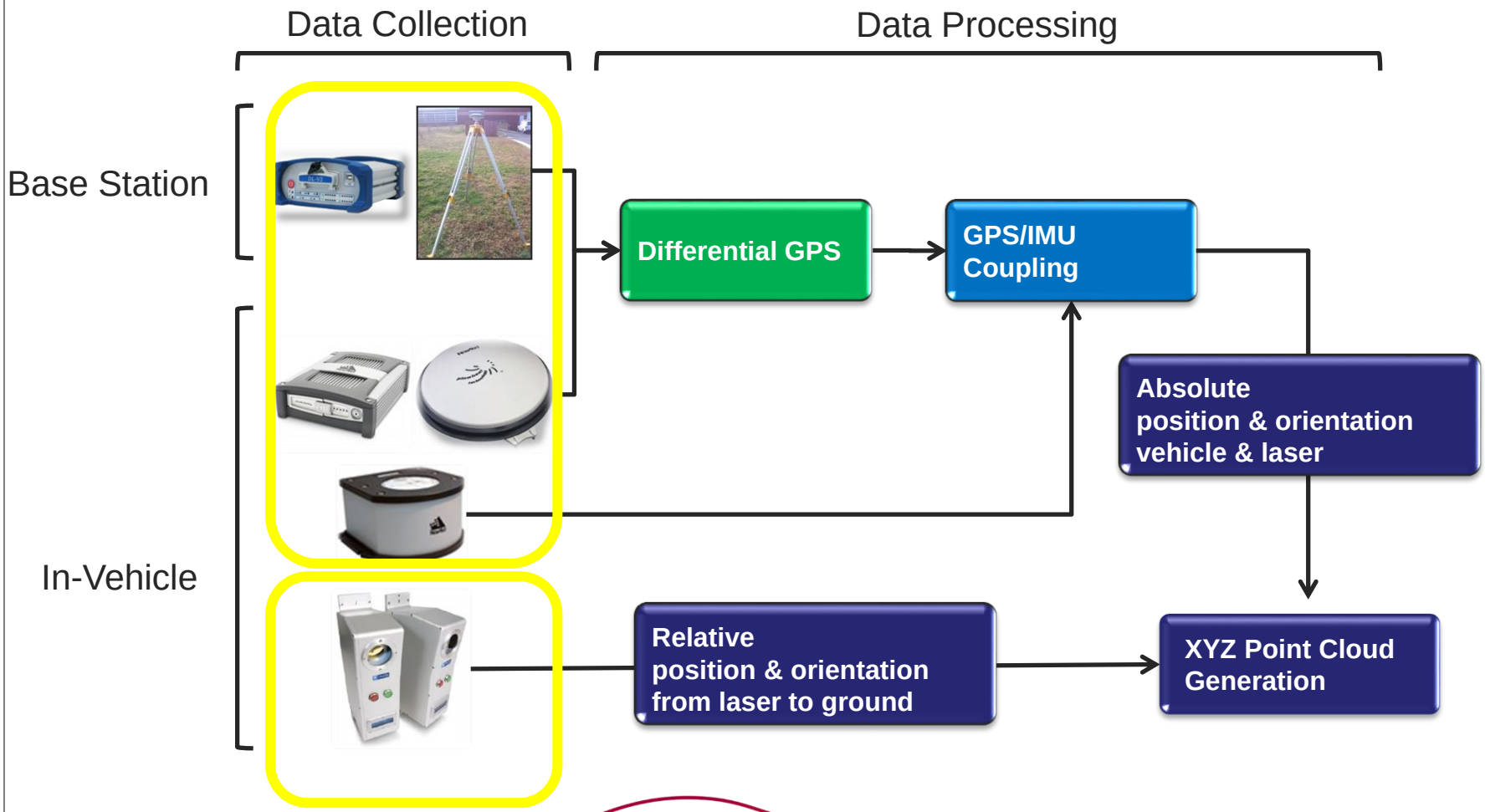
- Answering the question, “How accurate is this system?”
  - Traceable to ground truth
  - Statistically sound, but understandable
- Developing a process for informed, quantitative decisions
  - Cost/benefit analyses
  - Quality improvement plans

Questions?

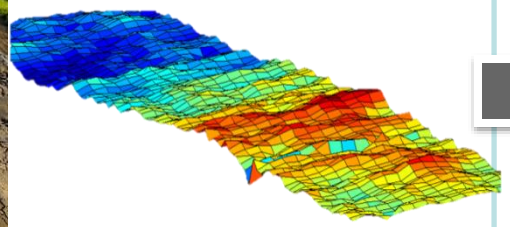
Thank you!

Backup Slides

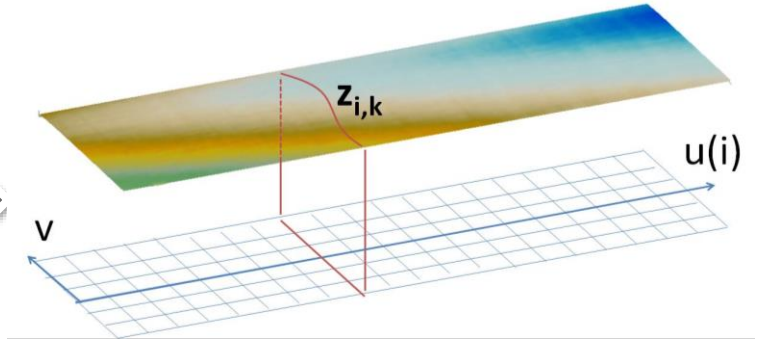
Terrain Surface Measurement



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

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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.

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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

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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

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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

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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

Frinkle, M., Weir, R., and Ferris, J. B., 2004, "A Graphical Representation of Road Profile Characteristics," Proceedings of the SAE World Congress, paper number 2004-01-0769, SAE, Detroit, MI.

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.

Saeger**, K. M., and Ferris, J. B., 2003, "Plausibility Checking of Road Profile Measurements," Proceedings of the SAE World Congress, paper 2003-01-0669, SAE, Detroit, MI.

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.

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*current or former student

** current or former intern