2020

WEBINAR SERIES

RPUG

Road Profile Users' Group

3D Technologies for Longitudinal Profile Measurements: Challenges to certification

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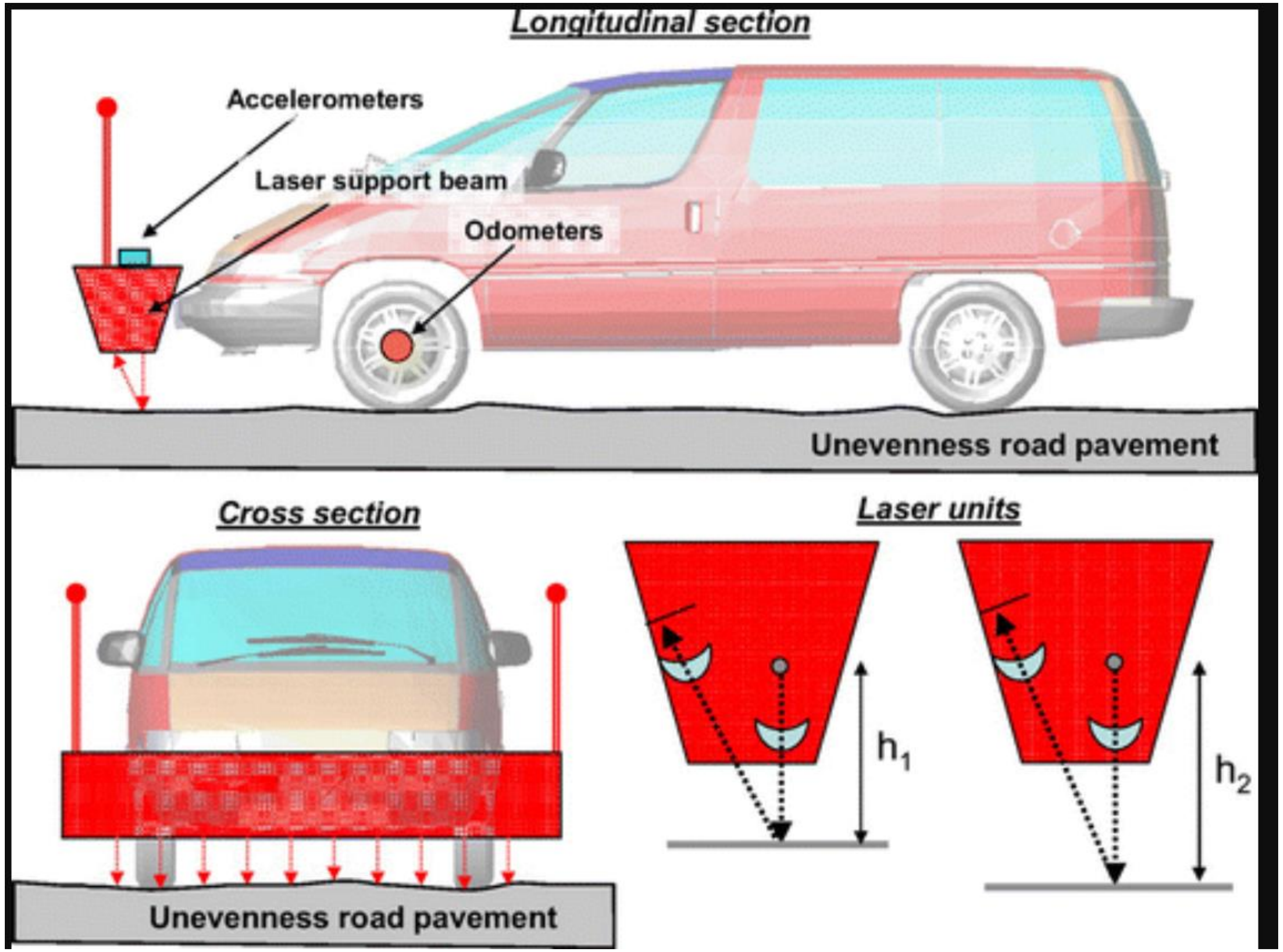
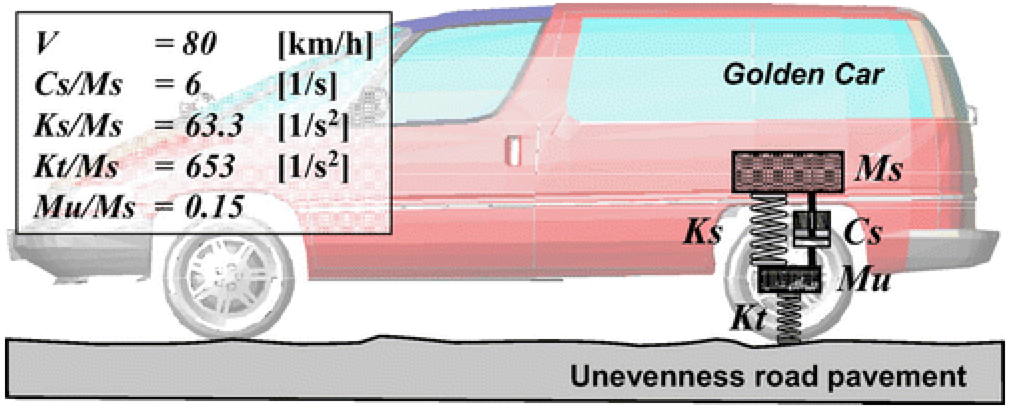
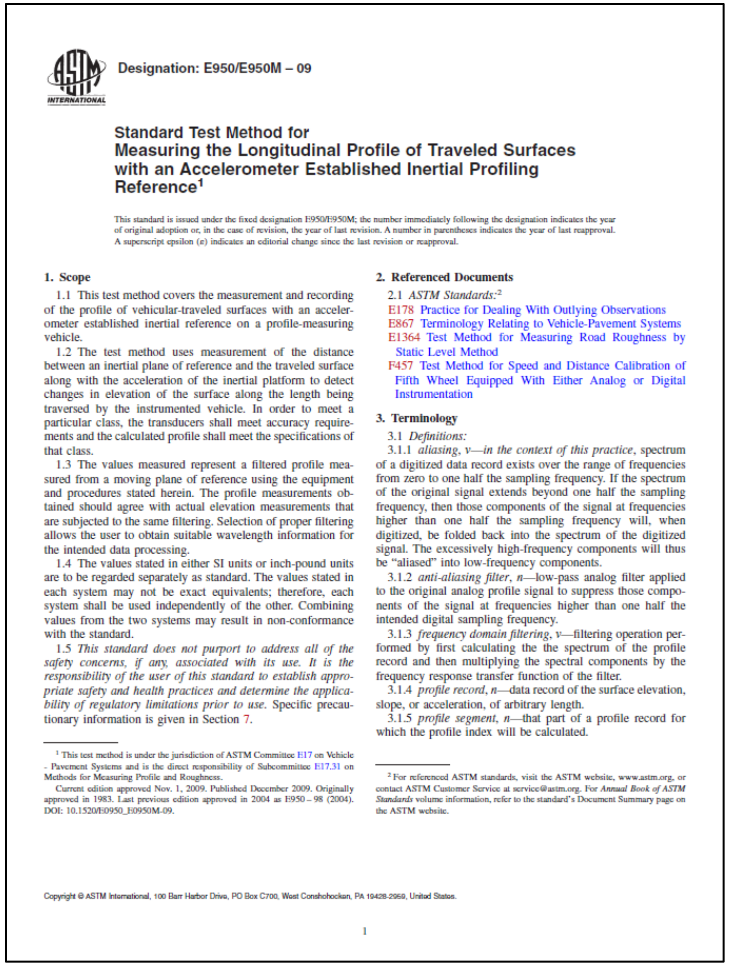
Profiler basic components (ASCE lib)





ASTM E950 - Longitudinal Profile



Designation: E950/E950M – 09

Standard Test Method for
Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference[1]

This standard is issued under the fixed designation E950/E950M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement and recording of the profile of vehicular-traveled surfaces with an accelerometer established inertial reference on a profile-measuring vehicle.

1.2 The test method uses measurement of the distance between an inertial plane of reference and the traveled surface along with the acceleration of the inertial platform to detect changes in elevation of the surface along the length being traversed by the instrumented vehicle. In order to meet a particular class, the transducers shall meet accuracy requirements and the calculated profile shall meet the specifications of that class.

1.3 The values measured represent a filtered profile measured from a moving plane of reference using the equipment and procedures stated herein. The profile measurements obtained should agree with actual elevation measurements that are subjected to the same filtering. Selection of proper filtering allows the user to obtain suitable wavelength information for the intended data processing.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary information is given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E178 Practice for Dealing With Outlying Observations
E867 Terminology Relating to Vehicle-Pavement Systems
E1364 Test Method for Measuring Road Roughness by Static Level Method
F457 Test Method for Speed and Distance Calibration of Fifth Wheel Equipped With Either Analog or Digital Instrumentation

3. Terminology

3.1 *Definitions:*

3.1.1 *aliasing, v—in the context of this practice*, spectrum of a digitized data record exists over the range of frequencies from zero to one half the sampling frequency. If the spectrum of the original signal extends beyond one half the sampling frequency, then those components of the signal at frequencies higher than one half the sampling frequency will, when digitized, be folded back into the spectrum of the digitized signal. The excessively high-frequency components will thus be "aliased" into low-frequency components.

3.1.2 *anti-aliasing filter, n*—low-pass analog filter applied to the original analog profile signal to suppress those components of the signal at frequencies higher than one half the intended digital sampling frequency.

3.1.3 *frequency domain filtering, v*—filtering operation performed by first calculating the the spectrum of the profile record and then multiplying the spectral components by the frequency response transfer function of the filter.

3.1.4 *profile record, n*—data record of the surface elevation, slope, or acceleration, of arbitrary length.

3.1.5 *profile segment, n*—that part of a profile record for which the profile index will be calculated.

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.31 on Methods for Measuring Profile and Roughness.

Current edition approved Nov. 1, 2009. Published December 2009. Originally approved in 1983. Last previous edition approved in 2004 as E950 – 98 (2004). DOI: 10.1520/E0950_E0950M-09.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

1

Class 1 Profiler:

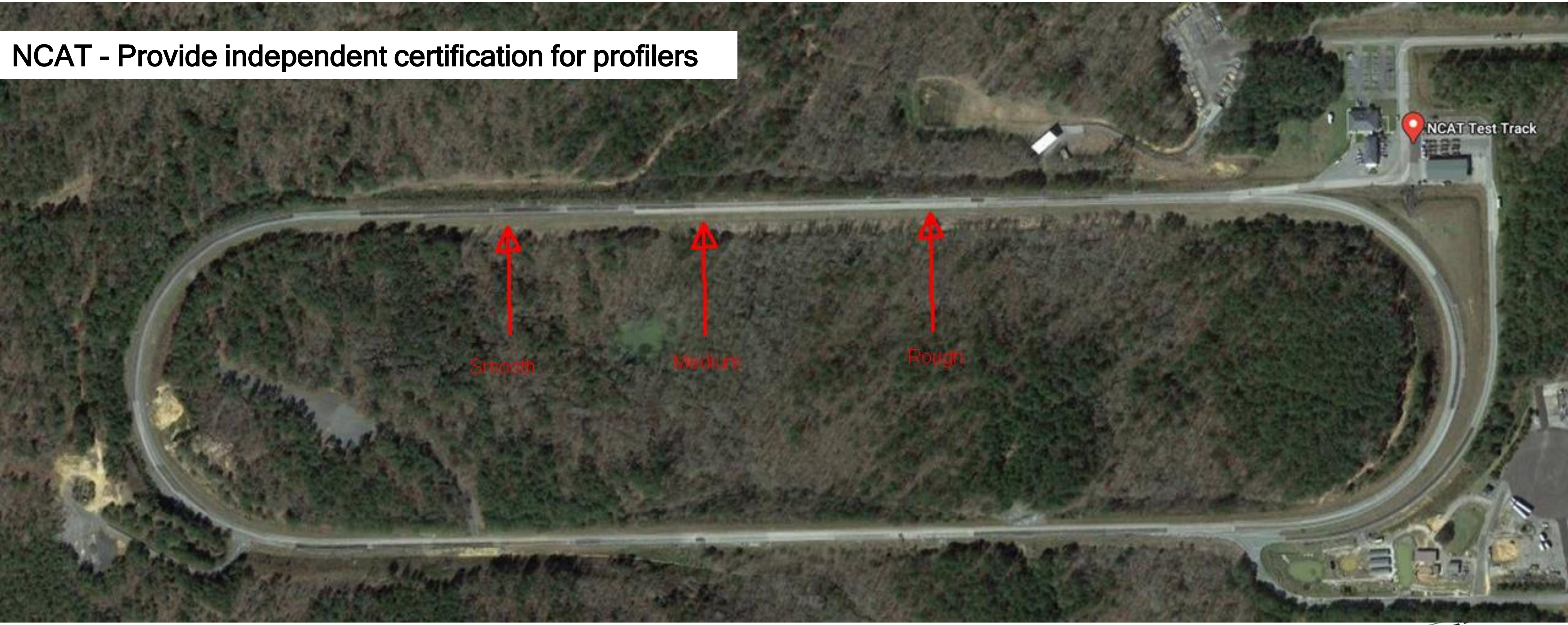
Longitudinal Sampling
Class 1 less than or equal to 25 mm [1 in.]

Vertical Measurement Resolution
Class 1 less than or equal to 0.1 mm [0.005 in.]

For 10 repeat runs (cross-correlation of profiles):

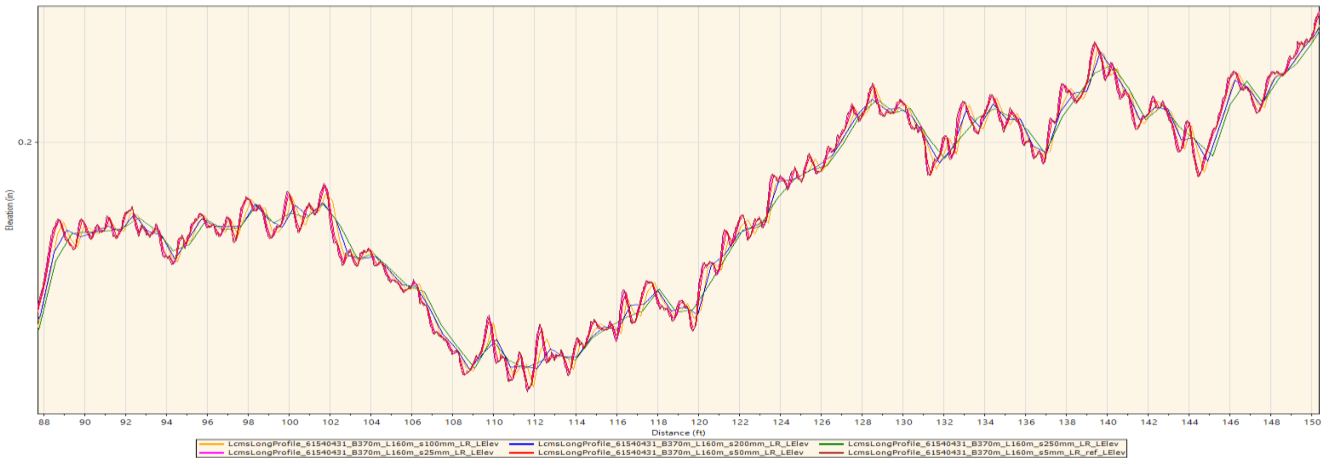
- Minimum 90% accuracy when compared to ground-truth (Surpro)
- Minimum 92% run-to-run repeatability

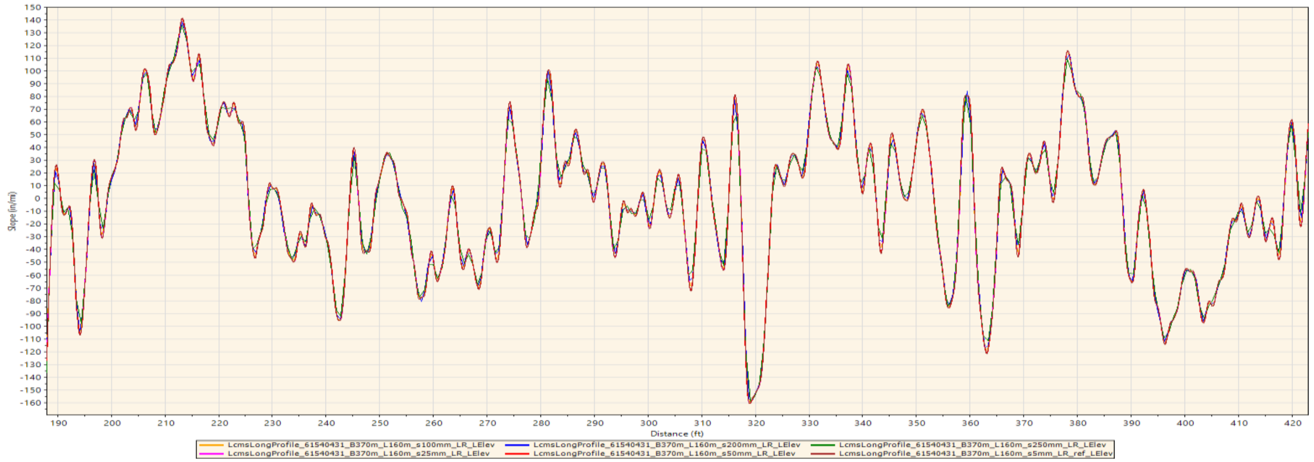
NCAT - Test Track Certification Site



How important is the 3D sensor? Effect of longitudinal spacing

Longitudinal spacing (mm)	Cross-Correlation (%)
5	100
25	99.97
50	99.83
100	98.88
200	97.80
250	96.14

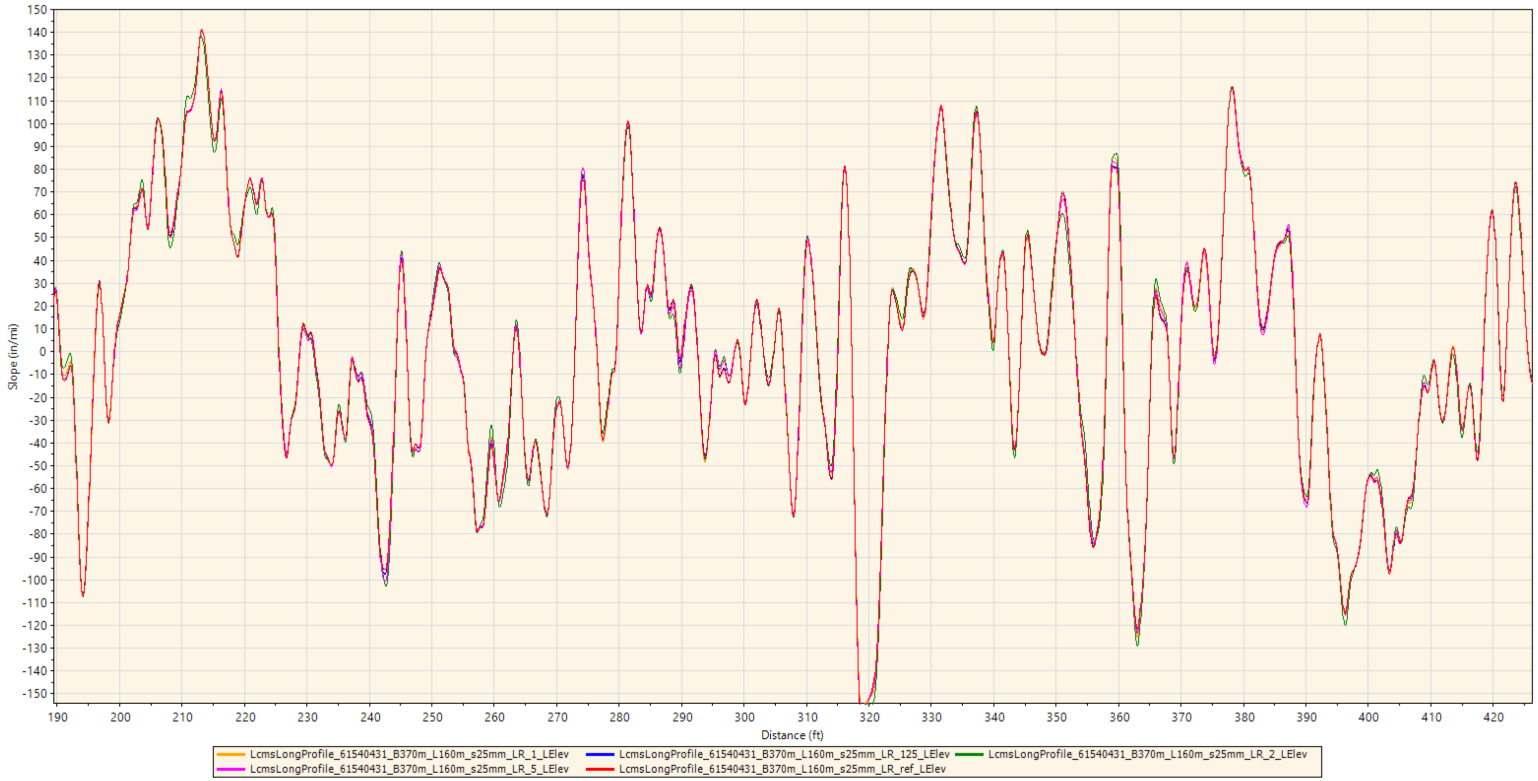




How important is the 3D sensor? Effect of range resolution.

Red curve is the reference (elevation profile after IRI filtering) other curves show different range resolutions.

The resolution of the range measurements were limited numerically in order to simulate the effect of the sensor range resolution on the accuracy results (cross-correlation).



Effect of a limited range resolution

- Results for the left wheel path of the smooth section at NCAT (IRI=43 in/mile).
- Limiting the sensor range resolution to 2 mm (or smaller) has little effect on the cross-correlation with the reference profile.

Range resolution (mm)	Cross-Correlation (%)
0.05	100
0.25	99.97
0.5	99.96
1	99.9
2	99.8
3	95.0
4	83.8

Effect of a limited range resolution

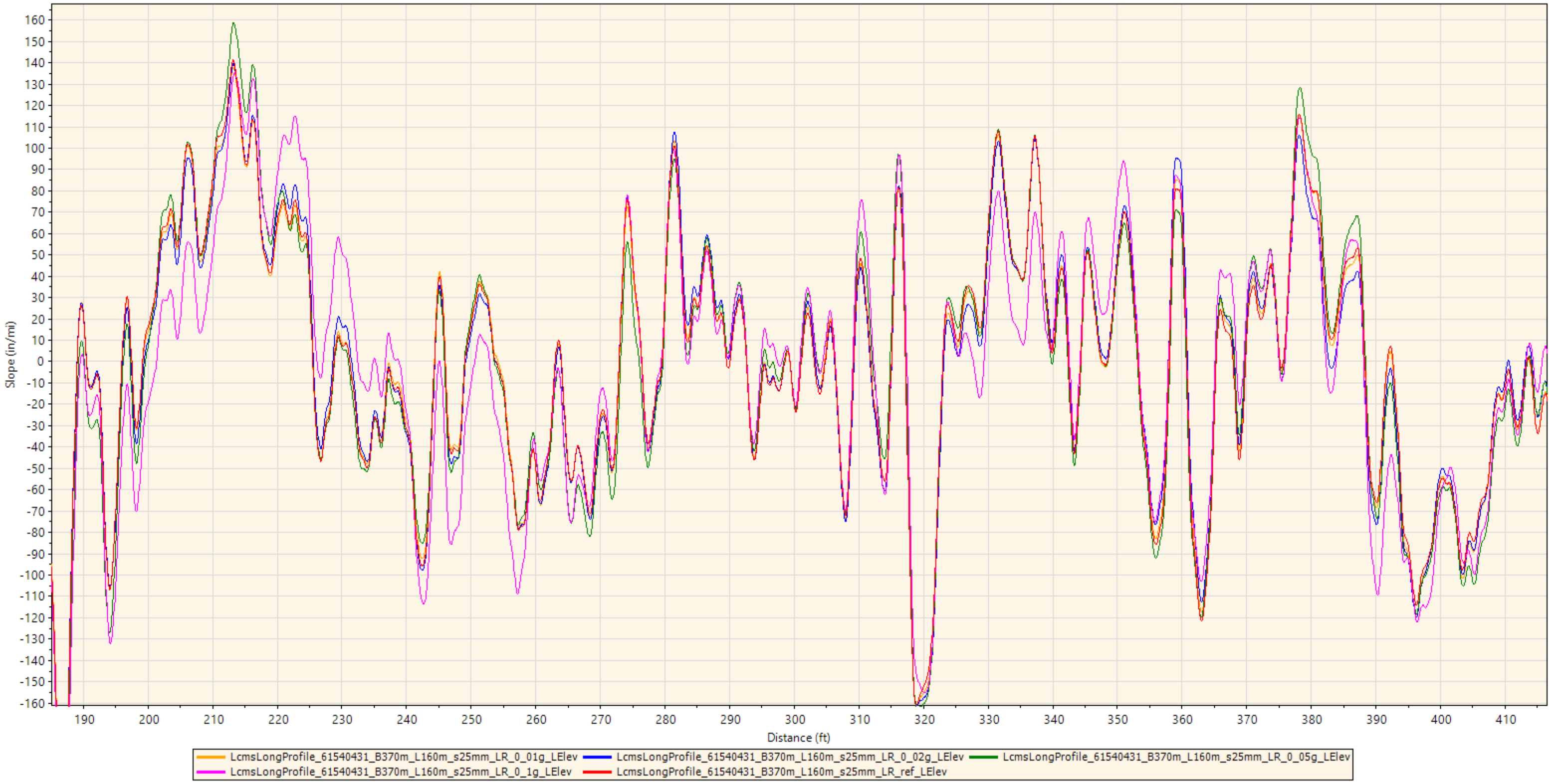
- Results for the left wheel path of the rough section at NCAT (IRI=167 in/mile).

Range resolution (mm)	Cross-Correlation (%)
0.05	100
0.25	99.98
0.5	99.97
1	99.96
2	99.93
3	99.40
4	98.01

How important is the accelerometer?

Red curve is the reference (elevation profile after IRI filtering) other curves show different accelerometer resolutions.

The resolution of the range measurements were limited numerically in order to simulate the effect of the accerelometer range resolution on the accuracy results (correlation).



Limited acceleration resolution

- Accelerometer used for test was mems based dynamic range: +/- 2g and resolution of 0.001g
- Resolution of acceleration measurements were limited numerically in order to simulate the effect of the acceleration resolution on the accuracy.

Resolution (g)	Cross-Correlation (%)
0.001	100
0.01	99.71
0.02	98.85
0.05	94.33
0.1	85.27

IRI vs accelerometers dynamic range

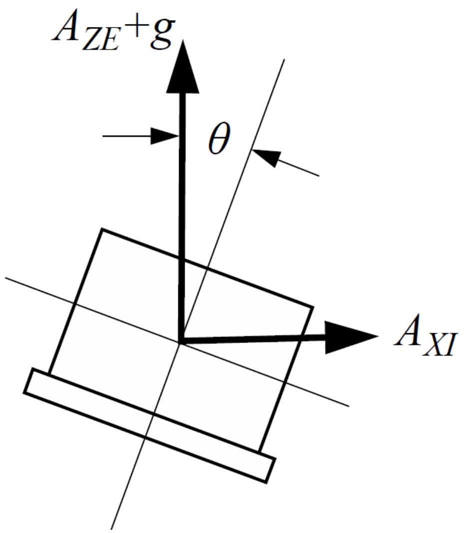
IRI values vs dynamic range for three road sections

	Section 1 (low roughness)		Section 2 (med. roughness)		Section 3 (high roughness)	
Range resolution (g)	Left IRI (in/mi)	Right IRI (in/mi)	Left IRI (in/mi)	Right IRI (in/mi)	Left IRI (in/mi)	Right IRI (in/mi)
±5	78	113	208	241	456	573
±3	78	113	208	241	456	573
±2	78	113	208	241	458	574
±1	78	111	210	240	460	587
Max. variation	0.0%	1.7%	0.9%	0.5%	1%	2.5%

Tilt error

- If the IMU is tilted this will introduce an error in the measurements.
- Cross-Correlation vs tilt angle (constant speed).

Tilt angle (degree)	Cross-Correlation (%)
1	99.99
2	99.95
3	99.88
4	99.79
5	99.67
10	98.70



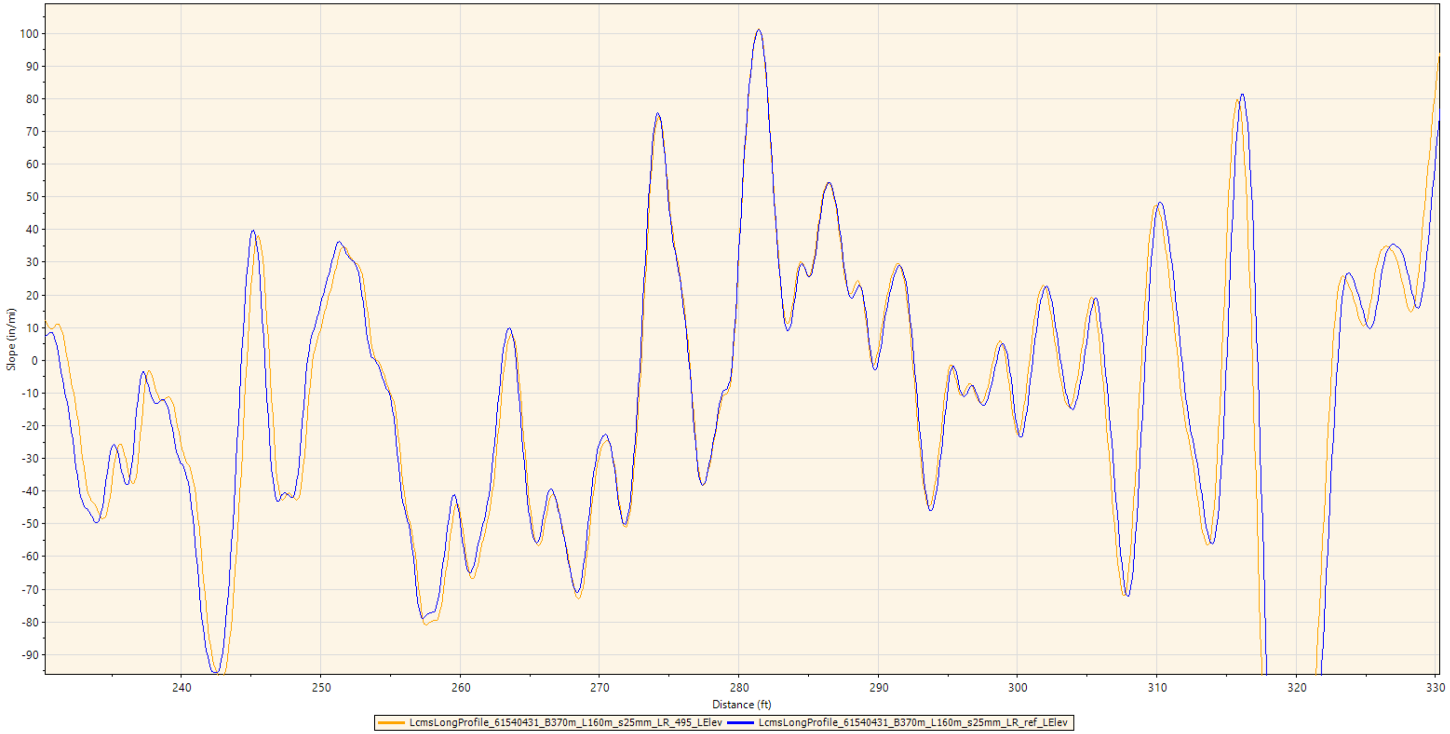
$$A_{ZV} = A_{XI}\sin(\theta) + (A_{ZE} + g)\cos(\theta) - g$$

$$A_{ZV} - A_{ZE} = A_{XI}\sin(\theta) + (A_{ZE} + g)(\cos(\theta) - 1)$$

Sayers, M. W. and S. M. Karamihas, *The Little Book of Profiling*

How important is the DMI?

- In this graph, the blue curve is the reference elevation profile after IRI filtering (slope).
- The yellow curve was generated from reference profile by changing the sampling step from 5.0 mm to 4.95 mm (1% change) to simulate an incorrectly calibrated DMI.



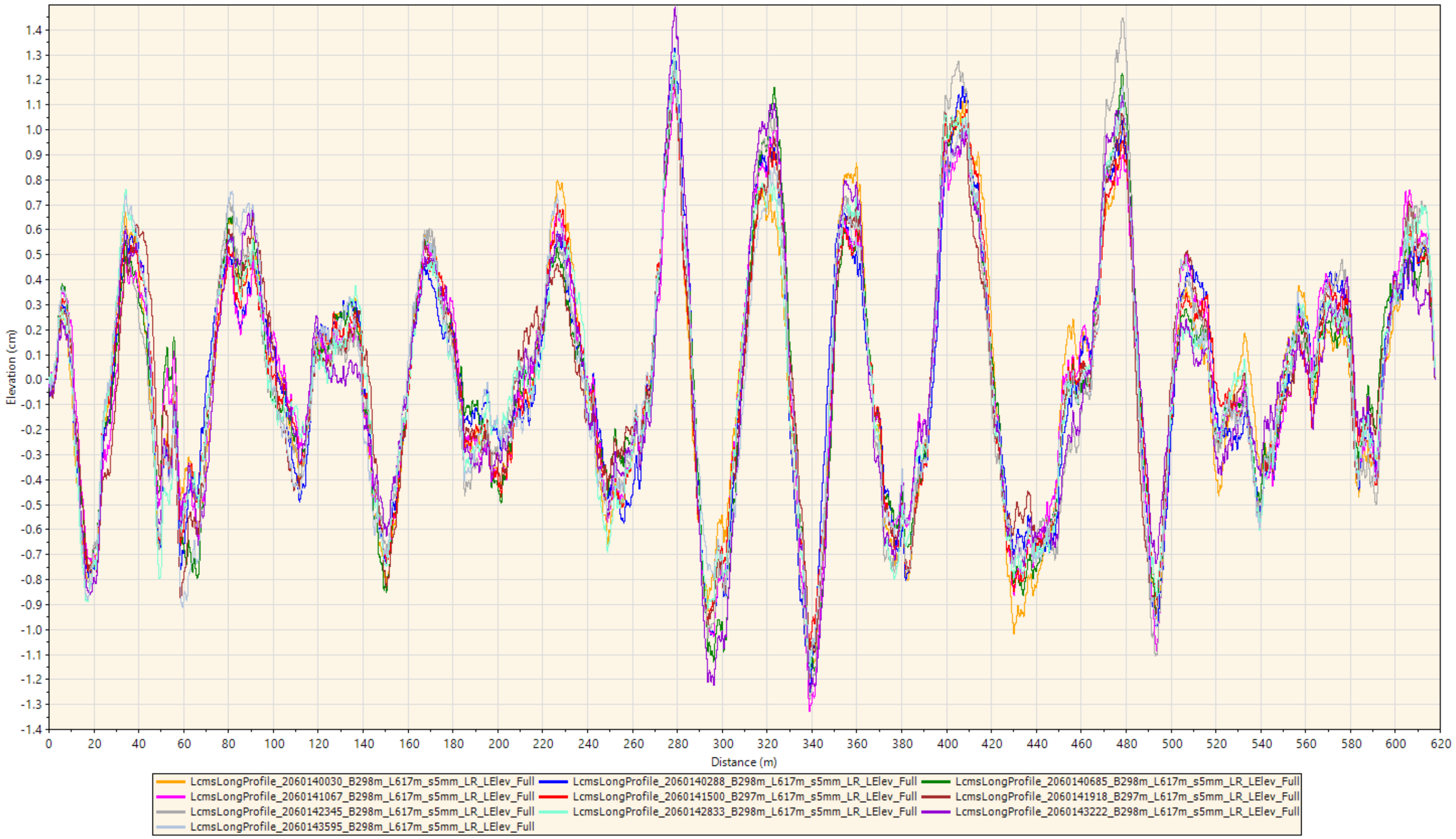
Effect of the DMI calibration

- The spacing of the reference profile was 5mm between points.
- A calibration error of the DMI of as small as 0.6% will make it impossible to pass the class 1 profiler certification.

Resolution (mm)	Variation (%)	Cross-Correlation (%)
4.99	0.2	98.6
4.98	0.4	95.0
4.97	0.6	90.4
4.96	0.8	85.4
4.95	1.0	80.4

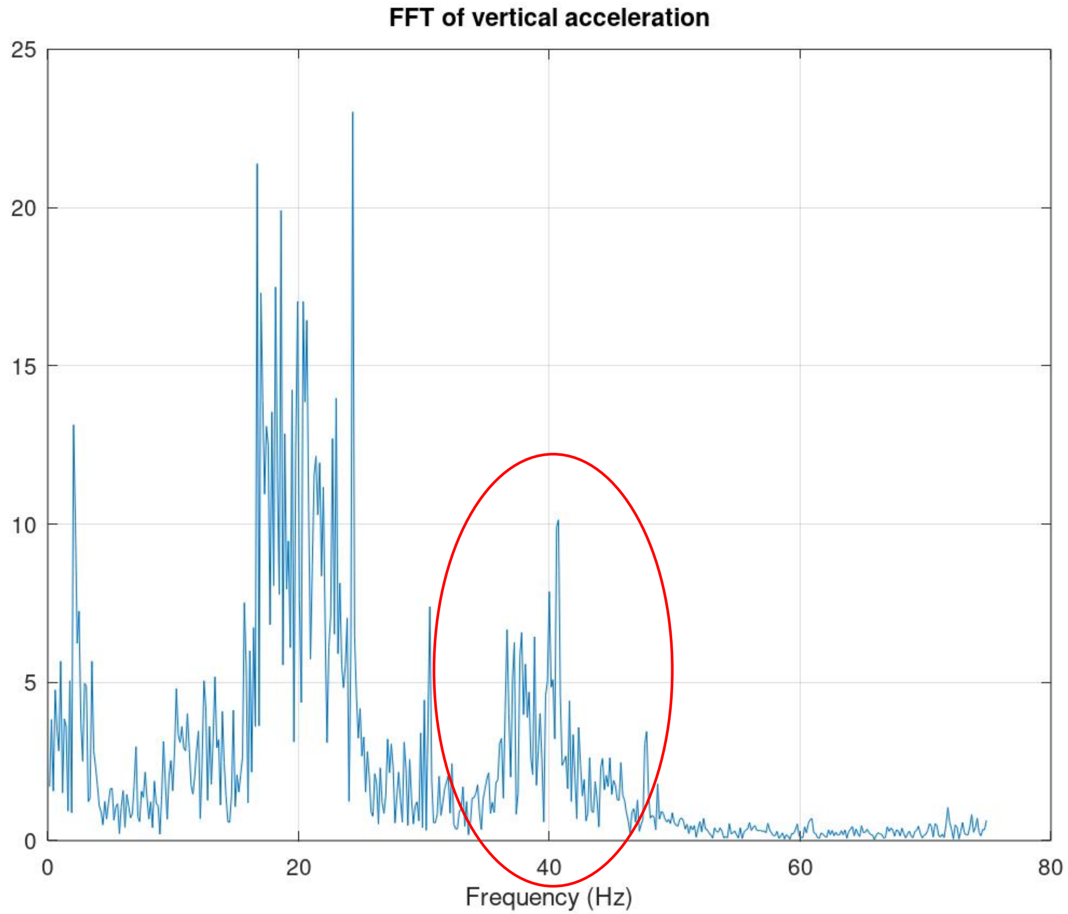
How important is the structure? (Vibration issues)

- The variability caused by the vibrations is visible in these elevation profiles.



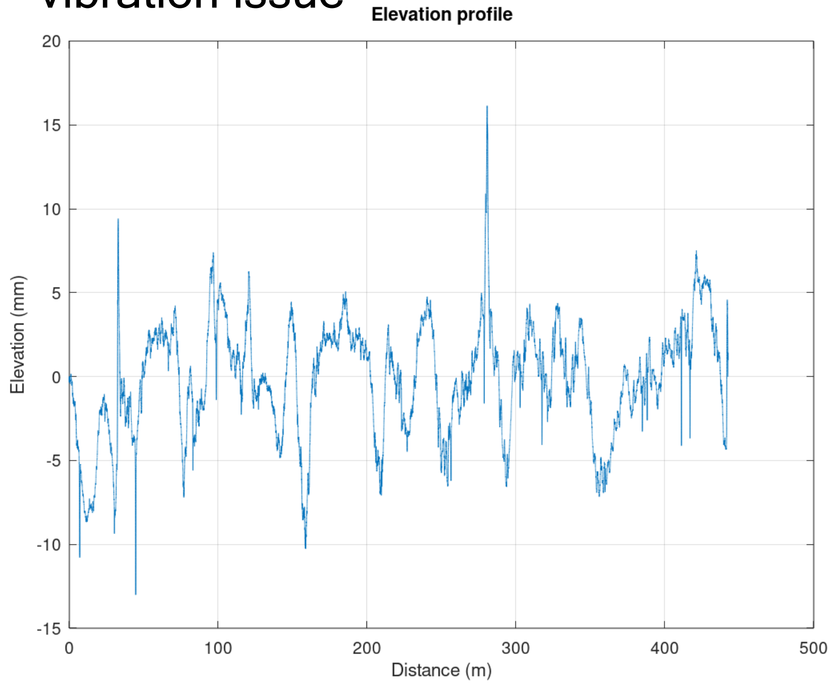
Vibration issue

- By doing the DFT of the vertical acceleration it is possible to identify vibration issues. Usually, there almost no energy after 20-25Hz. In this case, there is still energy present around 40Hz which degrades the repeatability.

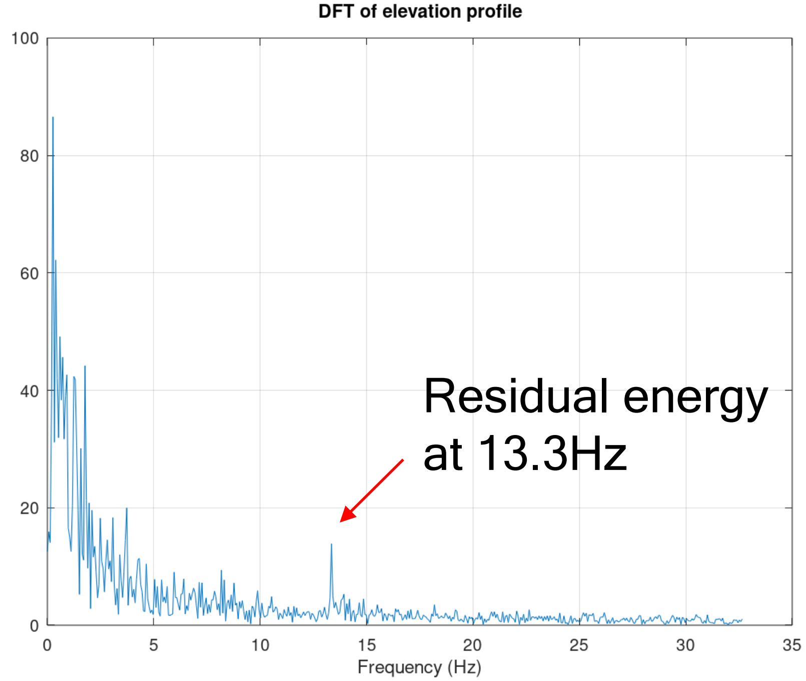


Elevation profile to DFT

Another example of applying a discrete Fourier transform (DFT) to the elevation profile allows us to detect another structure vibration issue



DFT

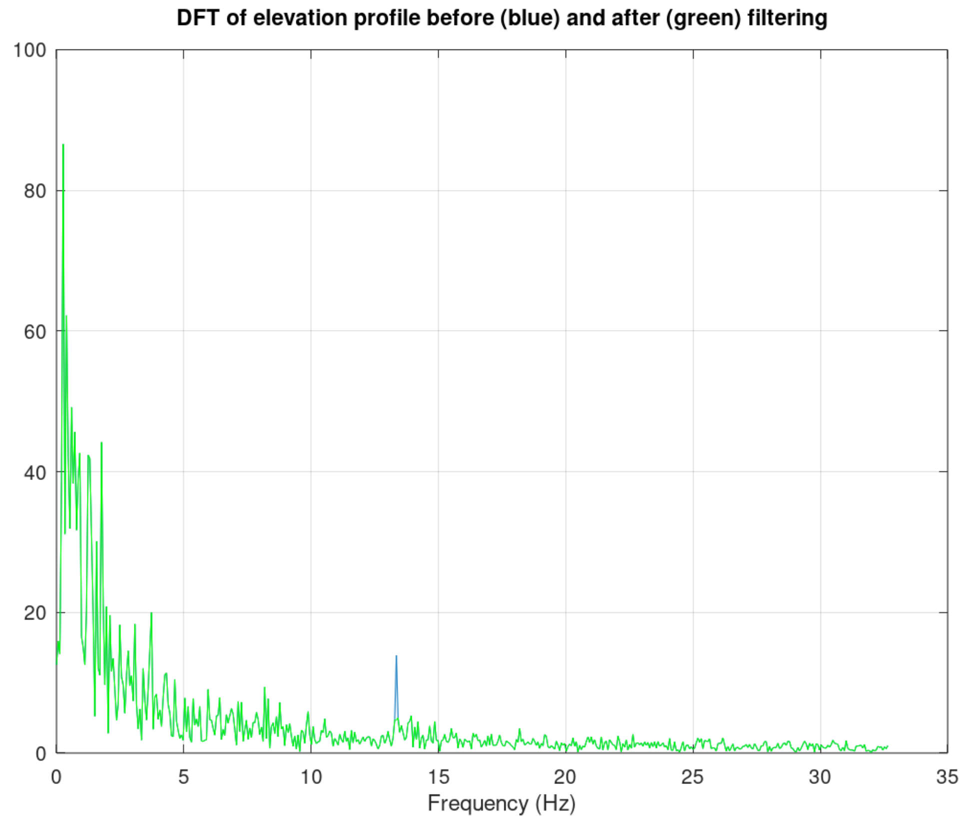


Filtering using the DFT

- To filter the residual effect of the vibrations, the value where the peak at 13.3Hz is replaced by the median value around it.

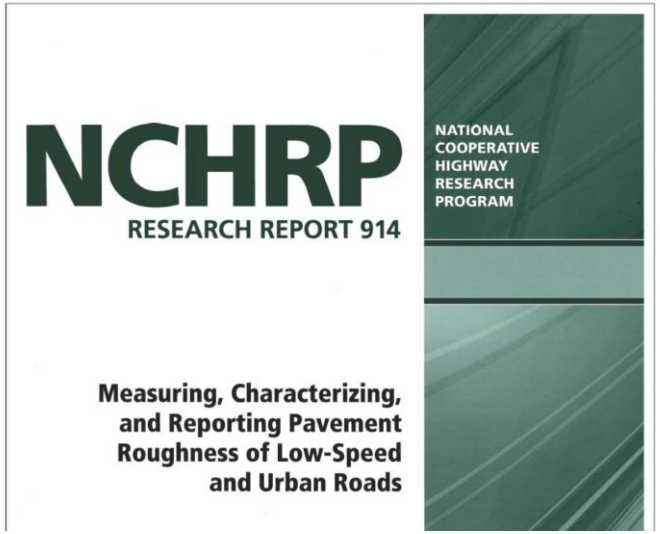
- The filtered elevation profile is obtained by applying the inverse DFT.

- The IRI for this 1452 feet section was 117.5 in/mi before filtering and 88.9 in/mi after. This value is consistent with results obtained when not contaminated by vibrations.



NCAT - Test Track Certification Site

Sensitivity to Lateral Tracking



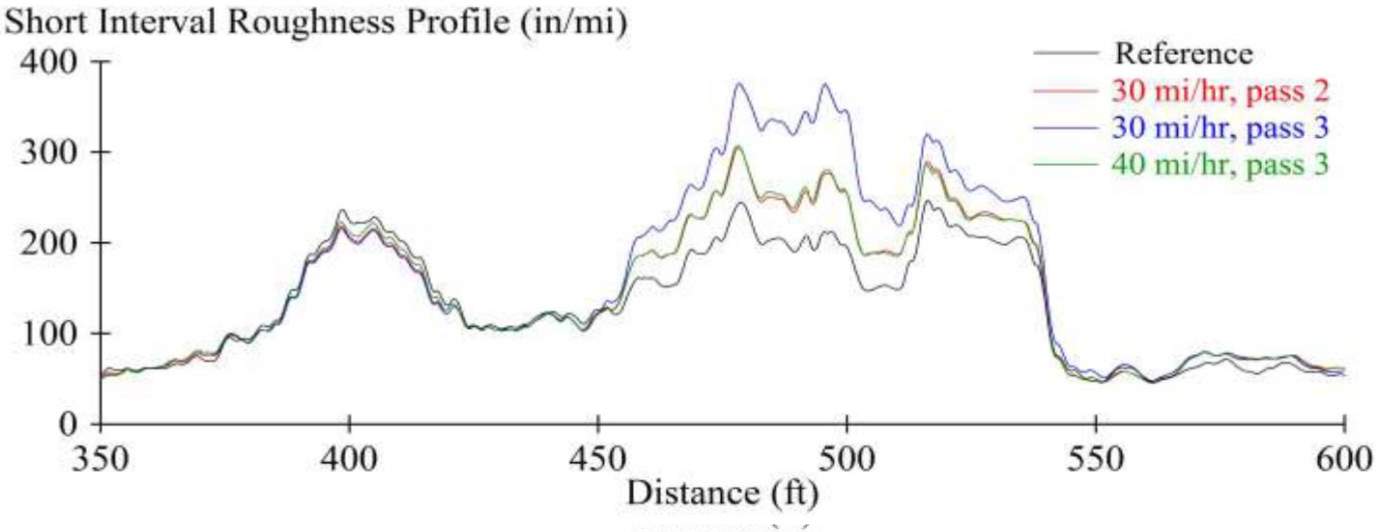


Figure 34. Roughness profiles of transversely inconsistent localized roughness.

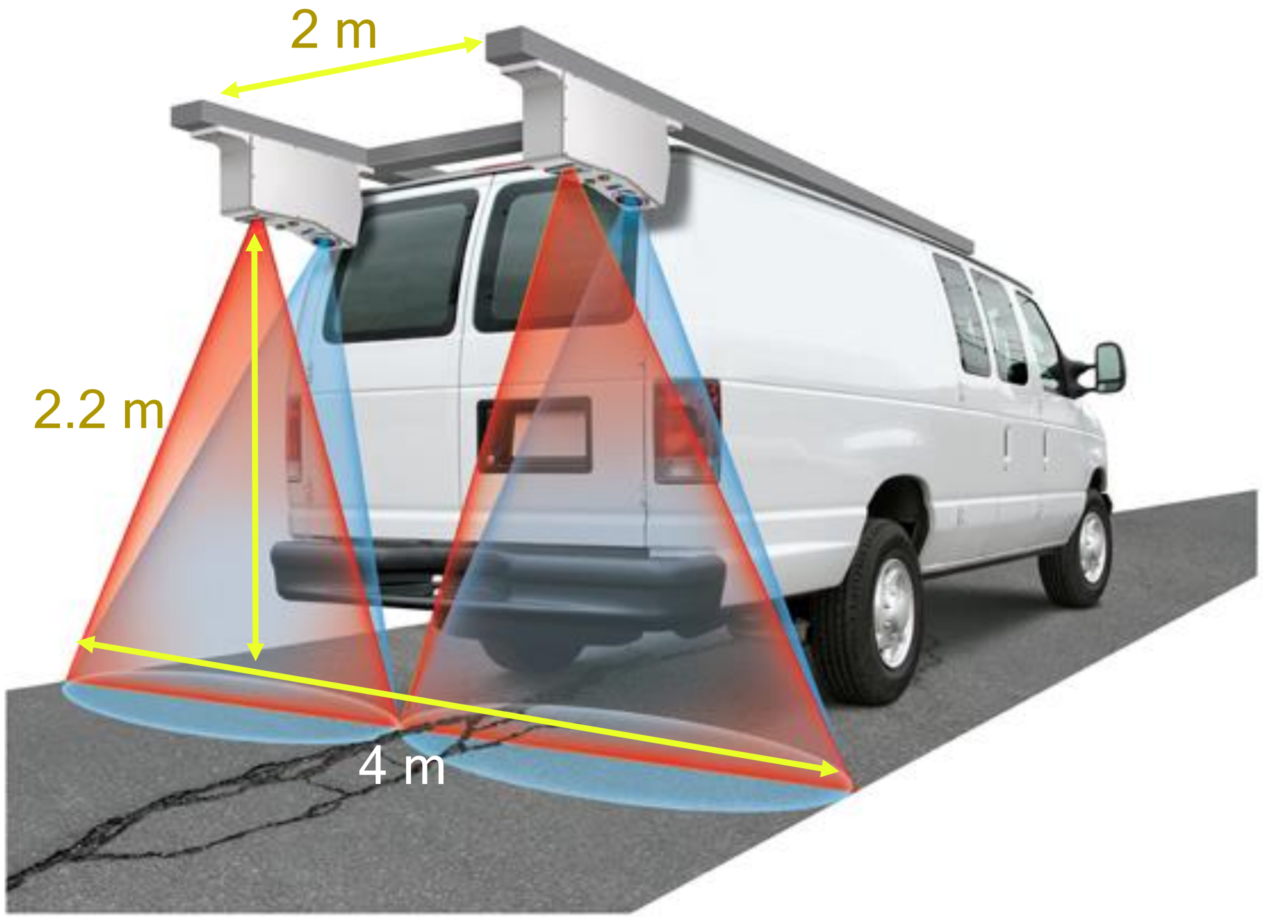
CHAPTER 5

Summary, Findings, and Recommendations:

Position records from a GPS data logging system showed that lateral tracking of the profilers strongly affected their repeatability and accuracy… for five of the six profilers.

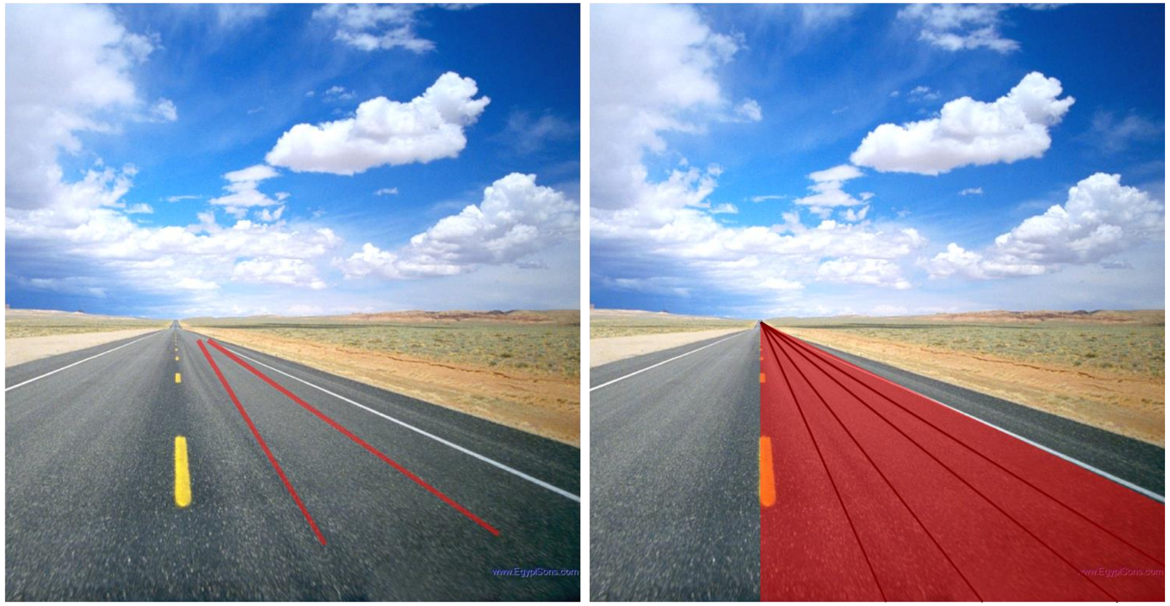
Pavemetrics

LCMS - Configuration



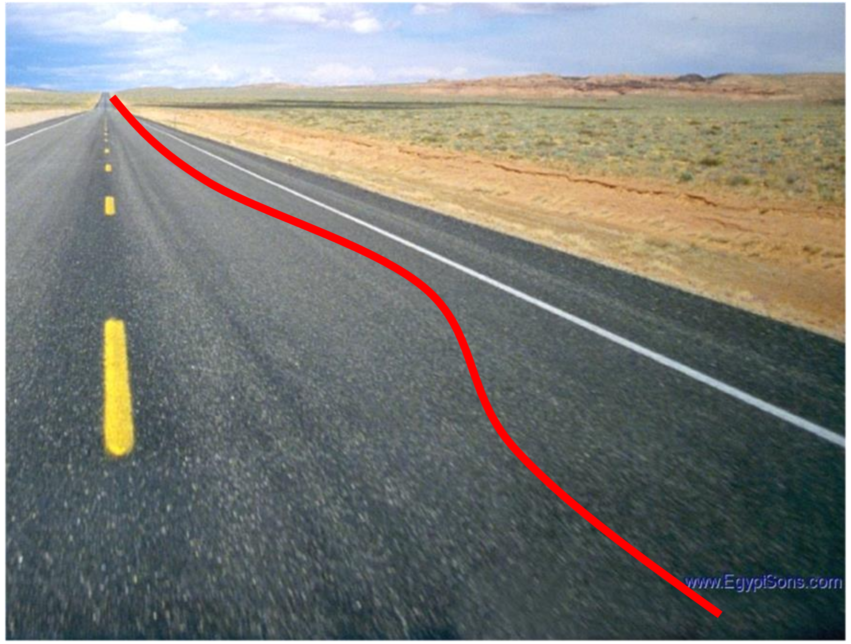
Pavemetrics

So How Does it Work with the LCMS?

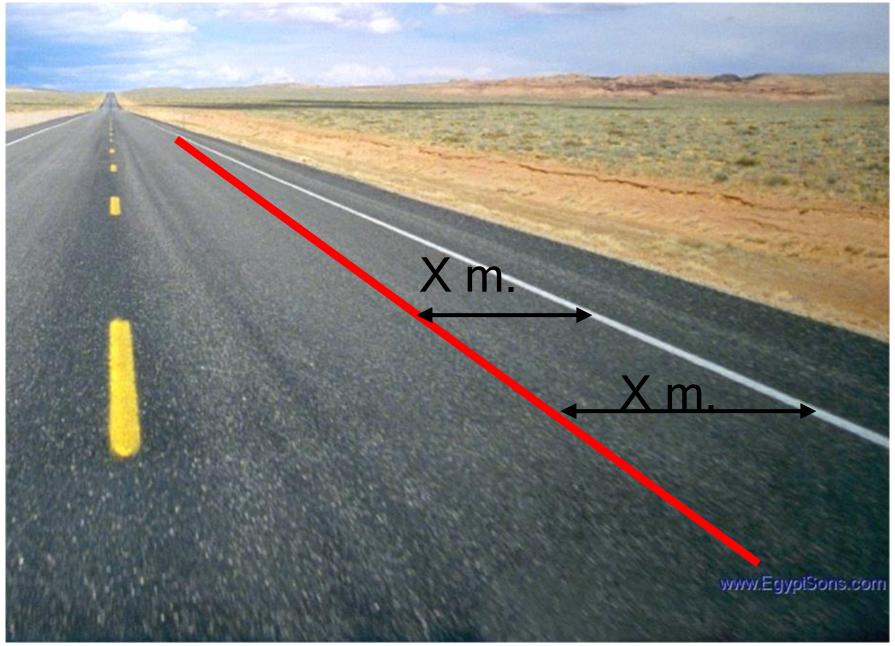


- 4m wide line lasers!
- 4,000+ points every 1mm
- Entire lane; not just a point or a small area
- IMUs are inside the LCMS sensors (accelerometers)

LCMS (Lane tracking)

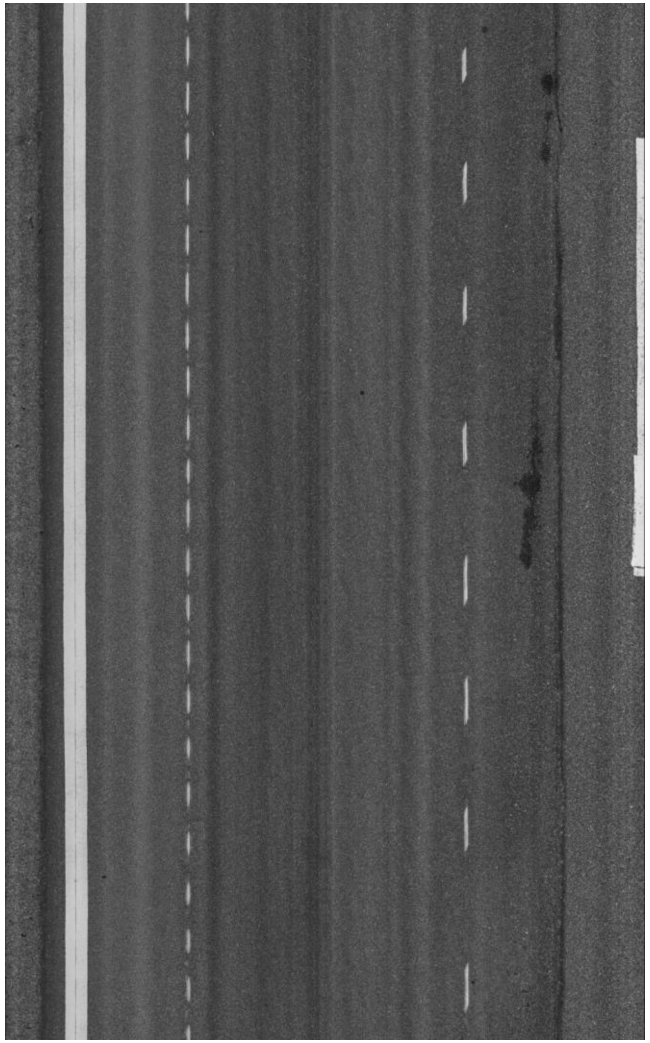


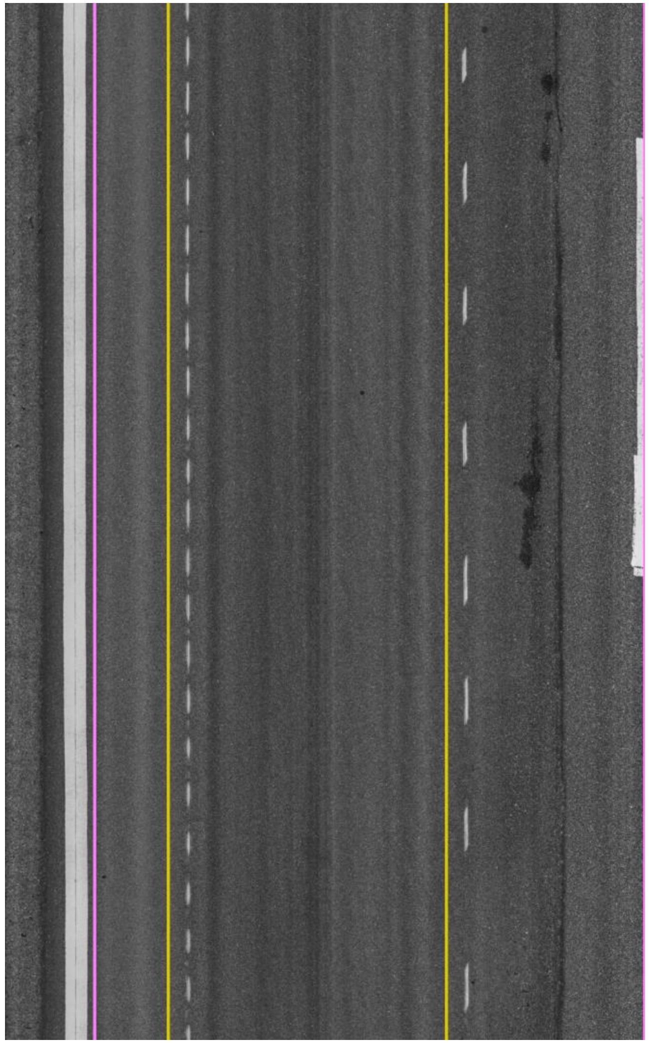
Classic system: Results depend on the trajectory of the vehicle (subject to variation based on driver's ability)



LCMS-IRI system: Erratic trajectory of the vehicle will still result in straight elevation profiles

NCAT - Test Track Certification Site

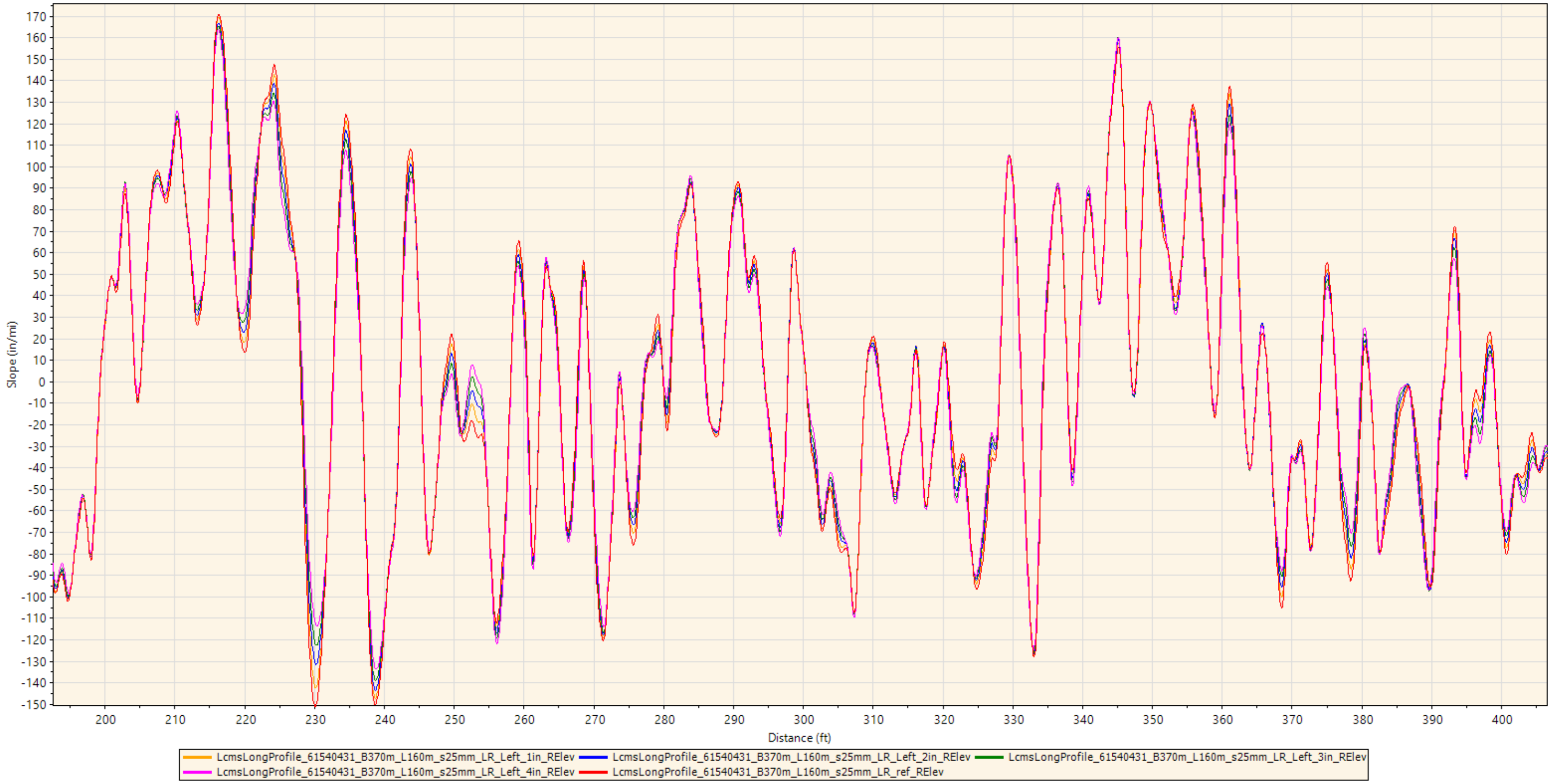




Effect of lateral shift

- The measurement position was shifted transversely by 1 inch increments with respect to the position of the reference profile.

Shift (inch)	Cross-Correlation (%)
1	99.1
2	98.1
3	97.0
4	96.0

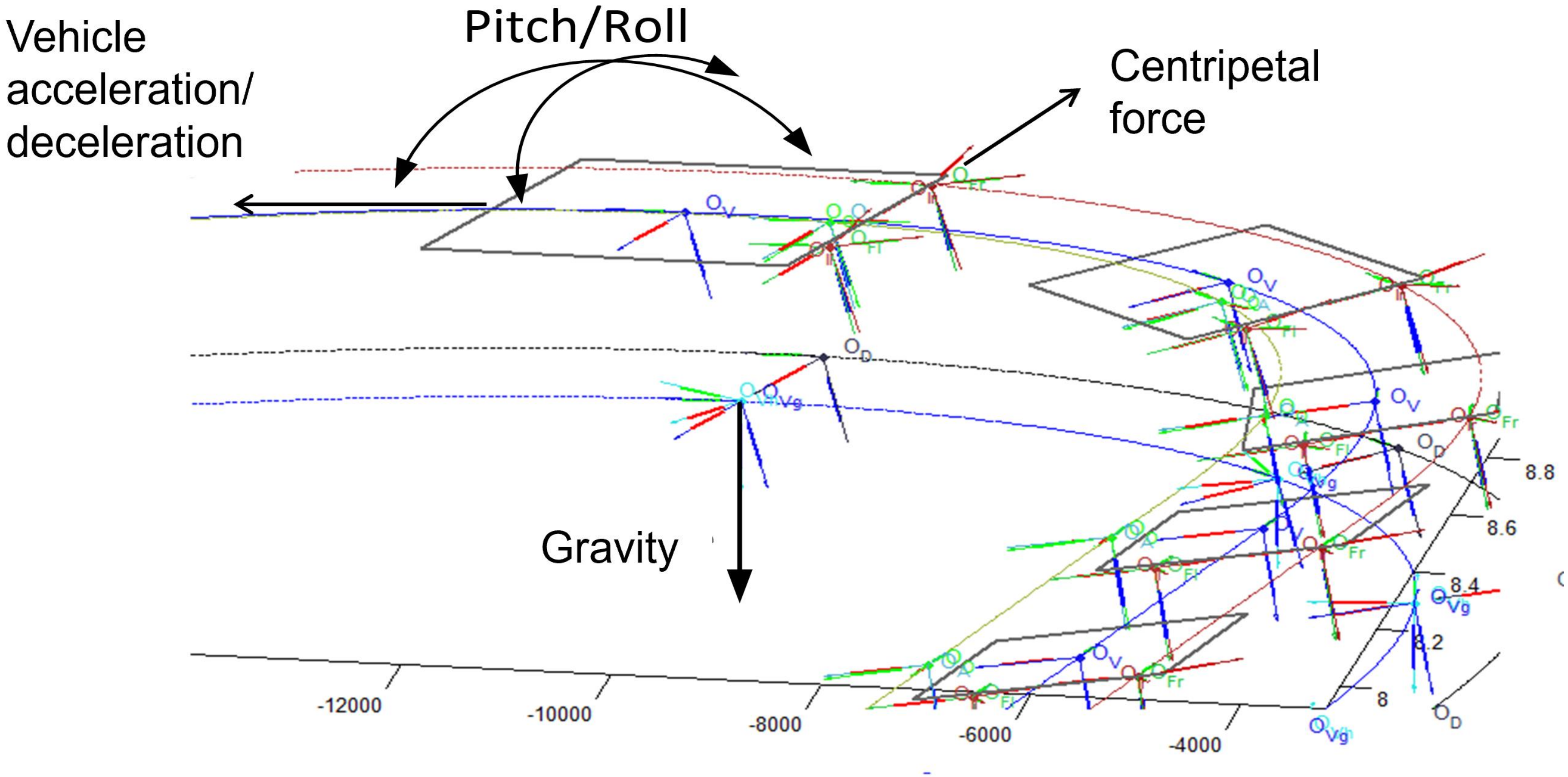


Pavemetrics

NCAT - Results - Class 1

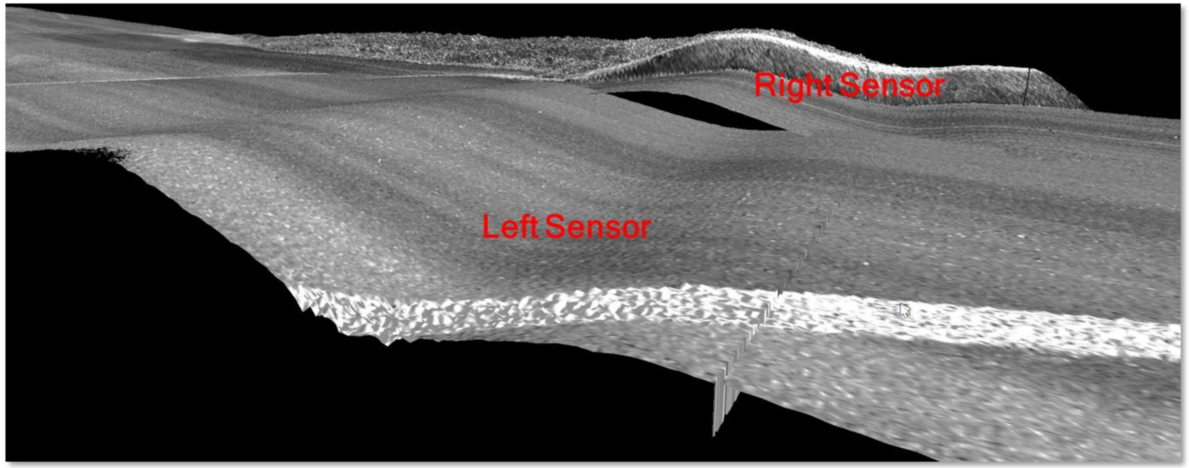
As of 2020 The LCMS has passed the NCAT Test Track roughness certification program and qualified as a Class 1 profiler 13 times!!

6 DOF Profiling!



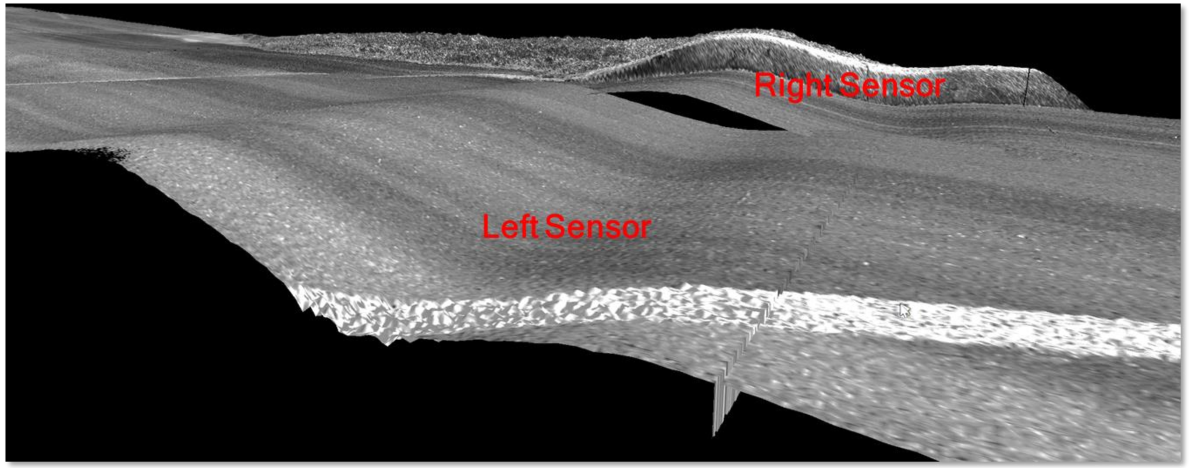
3D Road Profile Dynamic Corrections

Without Compensation

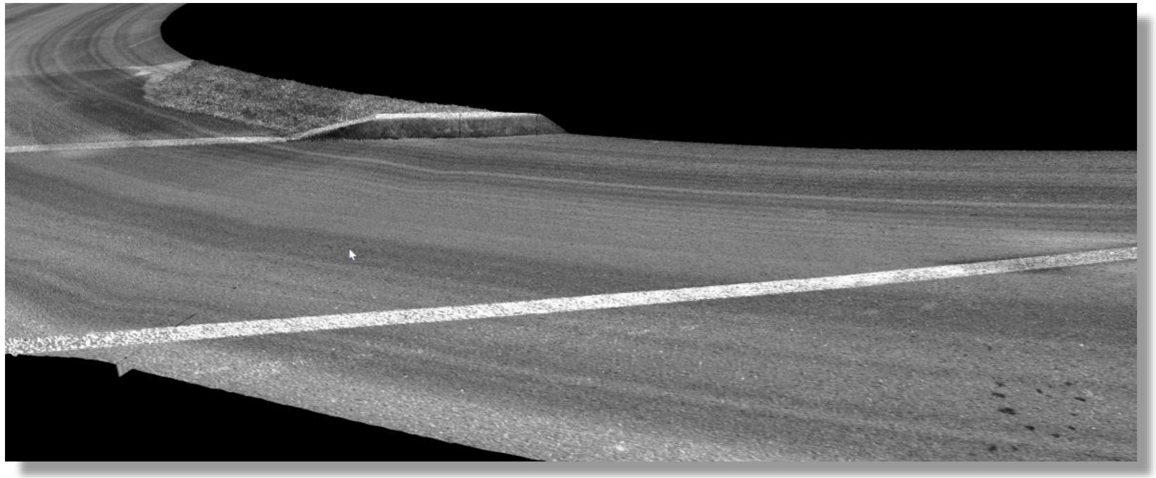


3D Road Profile Dynamic Corrections

Without Compensation



With Compensation



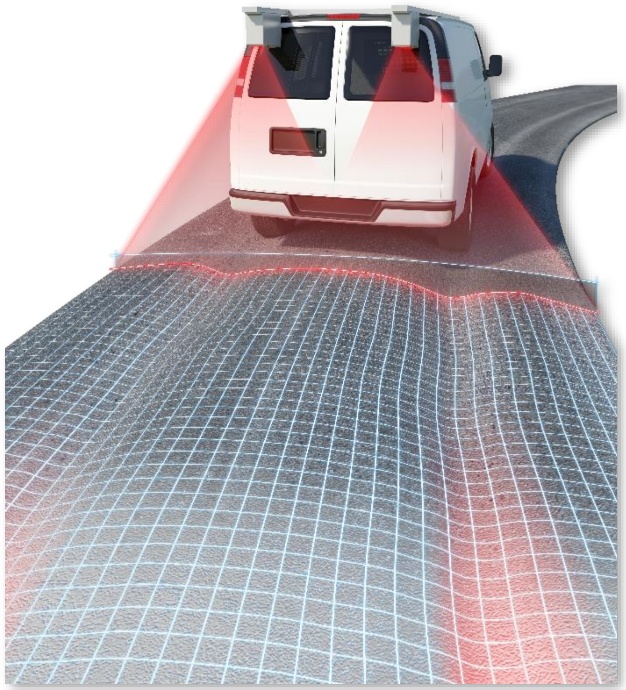
Pavemetrics LDTM solution

1. LCMS system

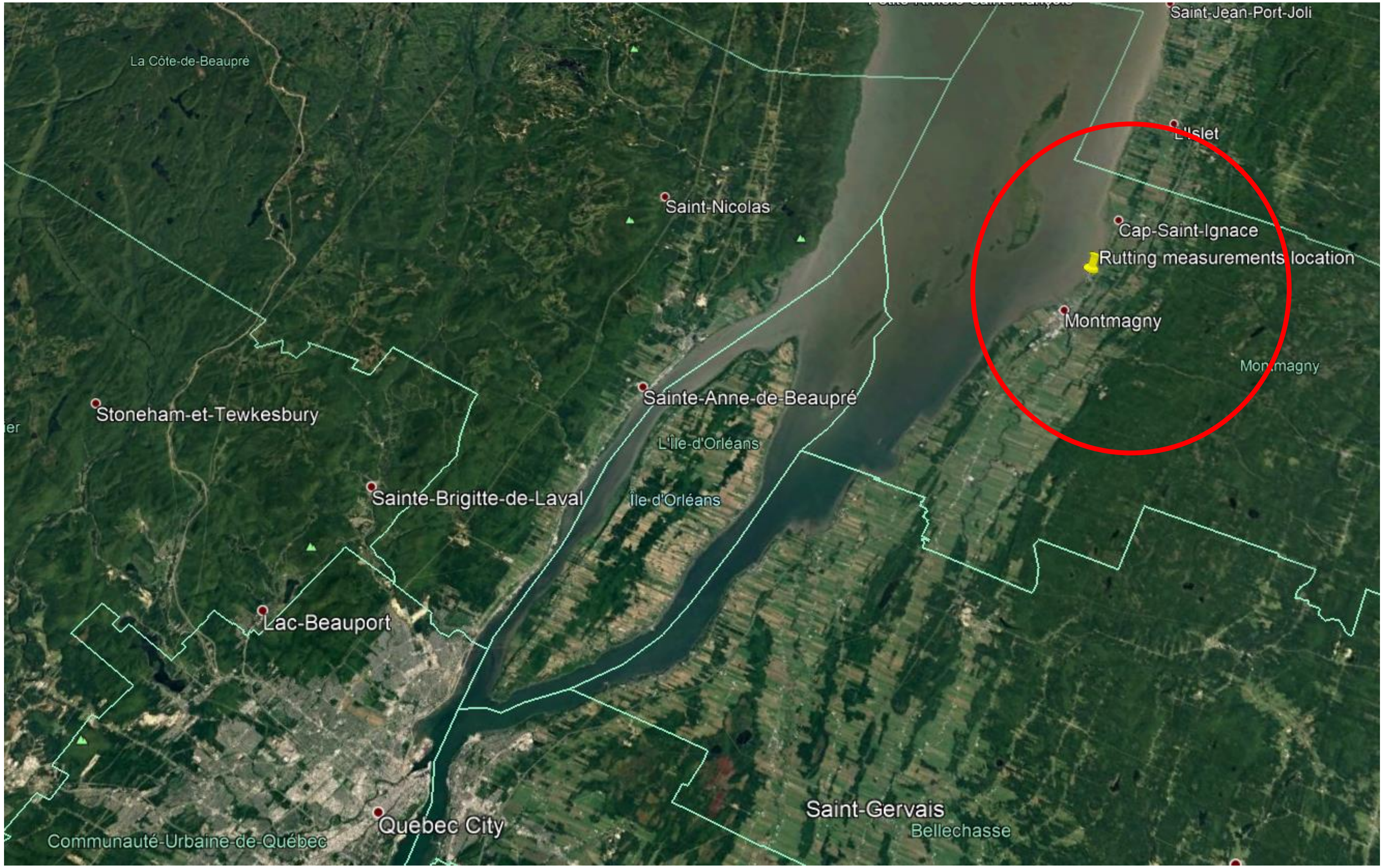
- 2 Laser profilers (4 meters field of view)
- 2 Inertial Measurement Units (IMU)
- Distance Measuring Instrument
- (DMI)

2. Applanix POS-LV

- Optical encoder (DMI)
- Inertial Measurement Unit (IMU)
- GNSS

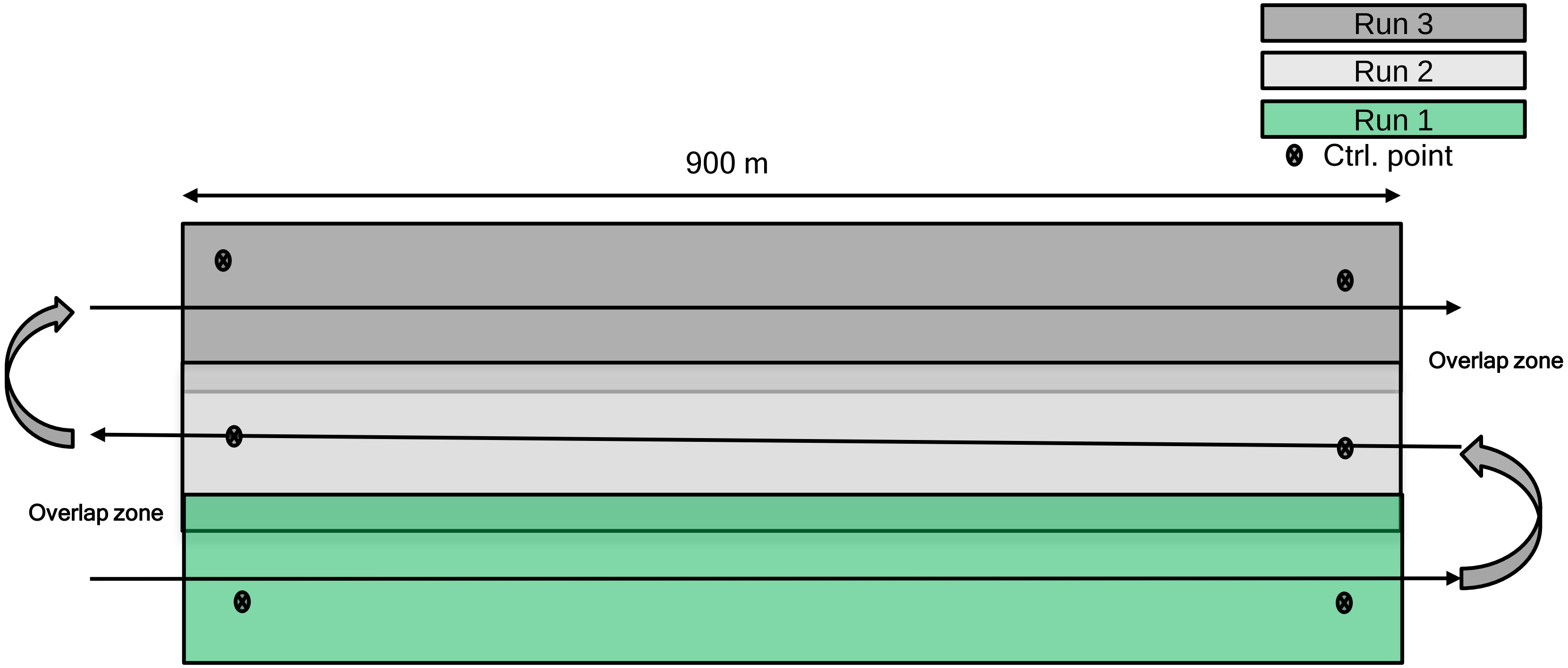


Montmagny airport

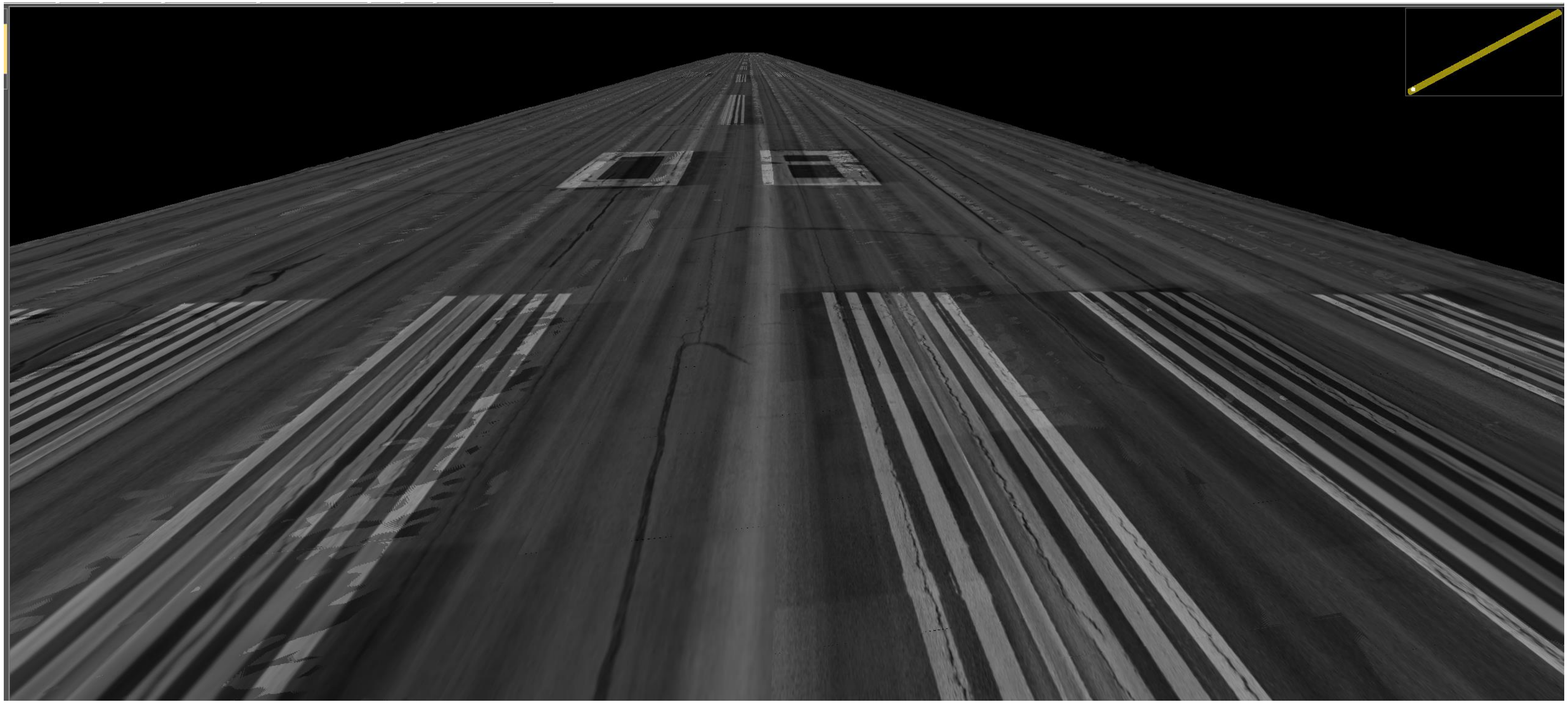


Runway 08-26, Montmagny, QC

Survey (11 runs with approx. 1m overlap between runs)



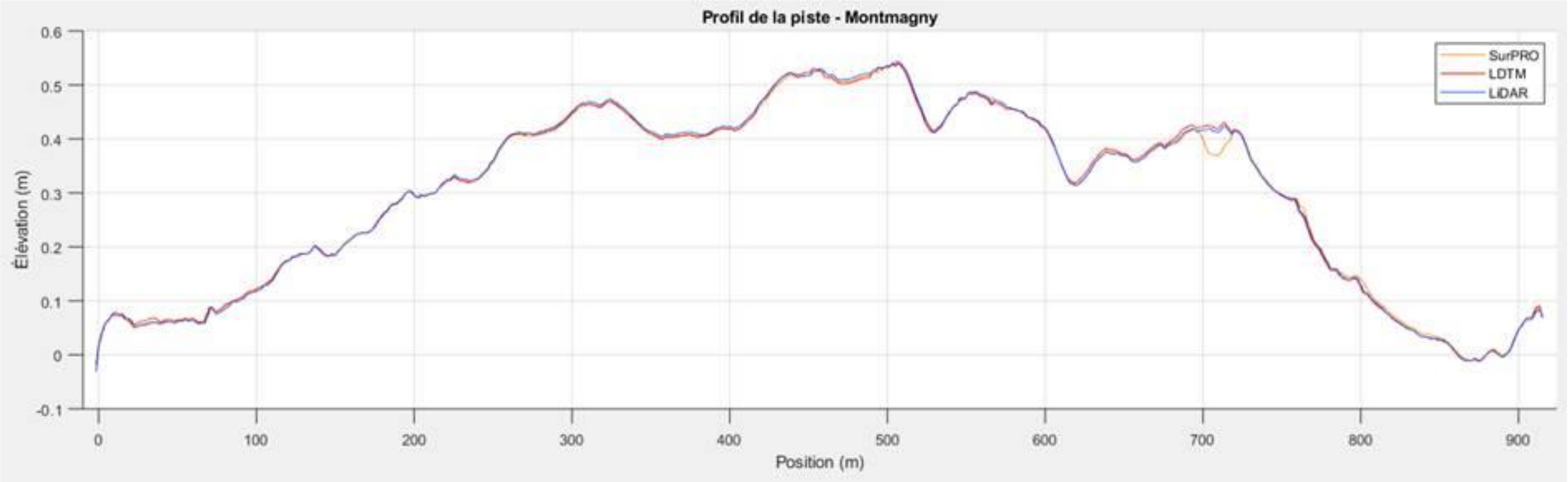
3D view of stitched runs



Longitudinal profile measured with Surpro and Leica P30 Lidar

Measured center line profile for the entire 900 m length of runway.

LCMS vs Lidar vs Surpro

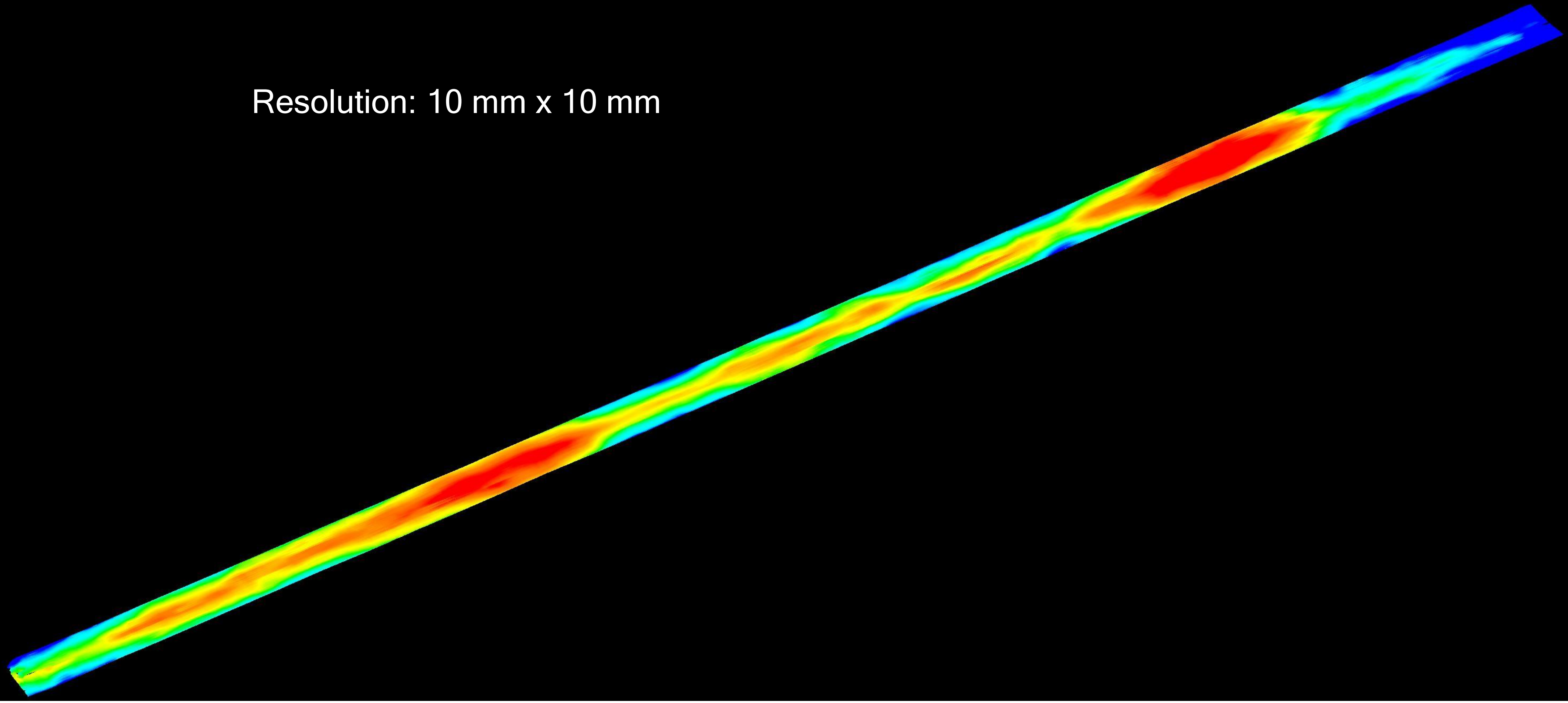


Site Location - Rutting

Elevation magnified by 10
One profile

Exported LAS file

Resolution: 10 mm x 10 mm



Conclusion

- Transverse position and odometer calibration are the most important factors to control.
- LCMS when properly configured and operated does pass the Class 1 E950 certification protocol
- E950-20 revision will certainly help (88% cross-correlation for Network level profilers).
- 6 DOF profiling with IMUs is the way to go for the future!
- 6 DOF allows profiling in slopes and curves, speed variations, and over pot holes.
- 6 DOF profiling is available NOW to LCMS-2 users !