



Pavemetrics

LCMS – Laser Crack Measurement System

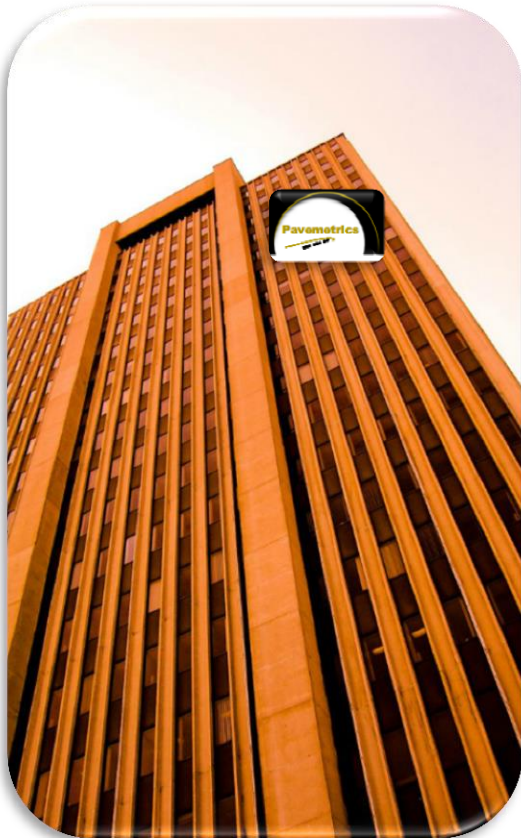
Vision Technology for Inspection of Transportation Infrastructures

PAVEMETRICS Systems Inc.

**150 Boulevard René-Lévesque Est, Suite 1820
Québec, Québec, CANADA
G1R 5B1**

www.pavemetrics.com

Pavemetrics; Infrastructure Vision Systems Specialists

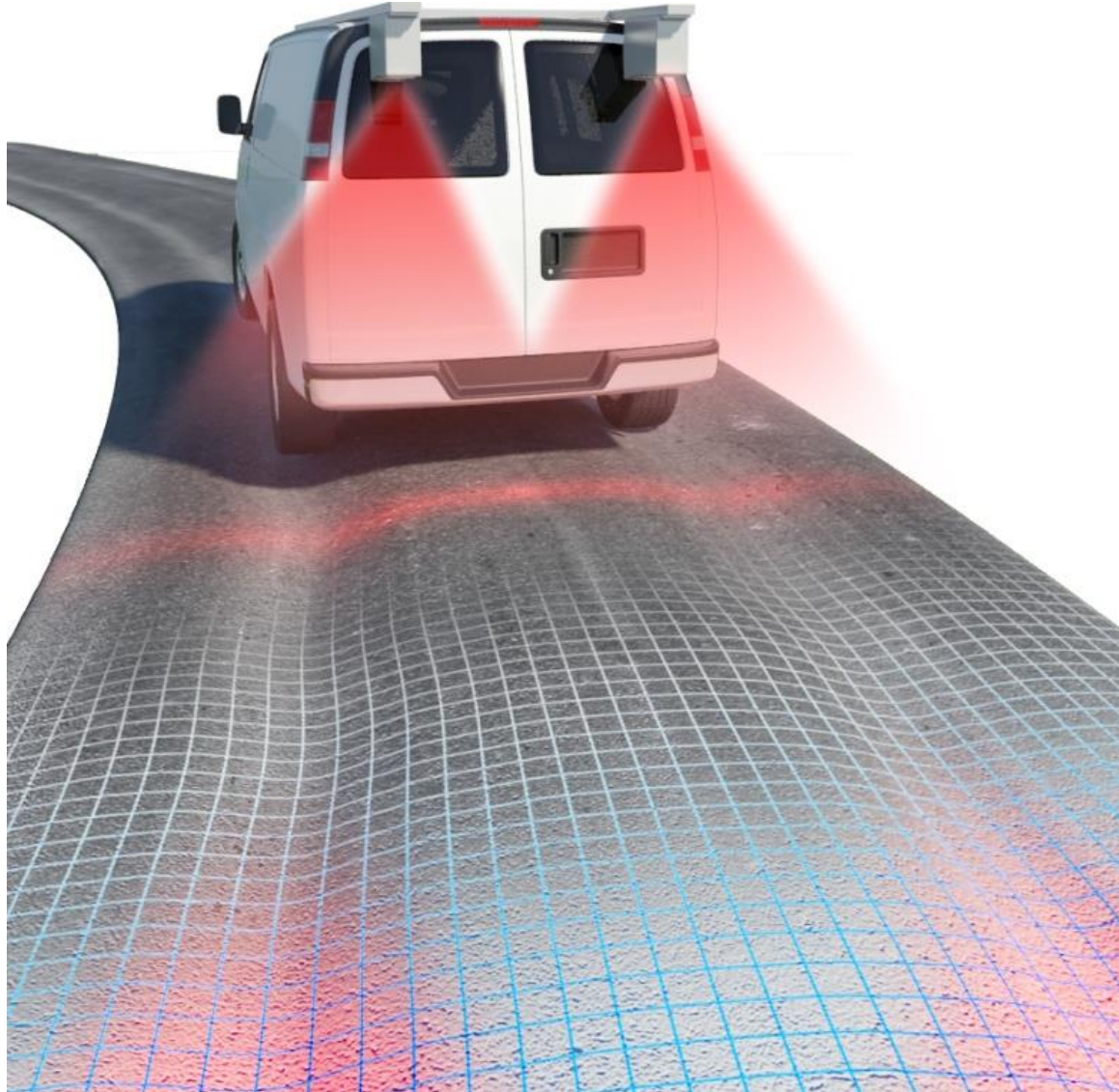


**Pavemetrics Headquarters
(Banque Nationale Bldg., QC)**

- **Founded 2009; a “Spin-off” of Canada’s National Optics Institute (INO)**
- **Develop high-speed, mm-level scanning and pattern analysis systems**
- **20,000,000+ Miles of Data Collected Since 1997**
- **300 Systems in 35+ countries**

Pavemetrics

Application: ROADS distress and DTM



Pavemetrics

The Sensor Technology Most Relied-on by DOTs worldwide



Collect Your Own, or Contract-out

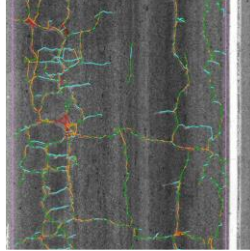


NOT a prototype

Certified AND proven around the world.

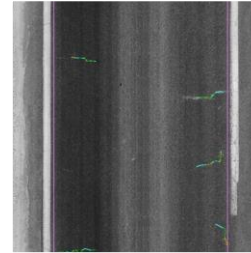


Any Paved Surface

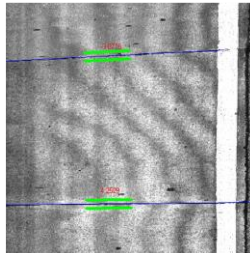


Hotmix

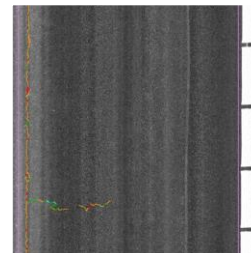
Chipseal

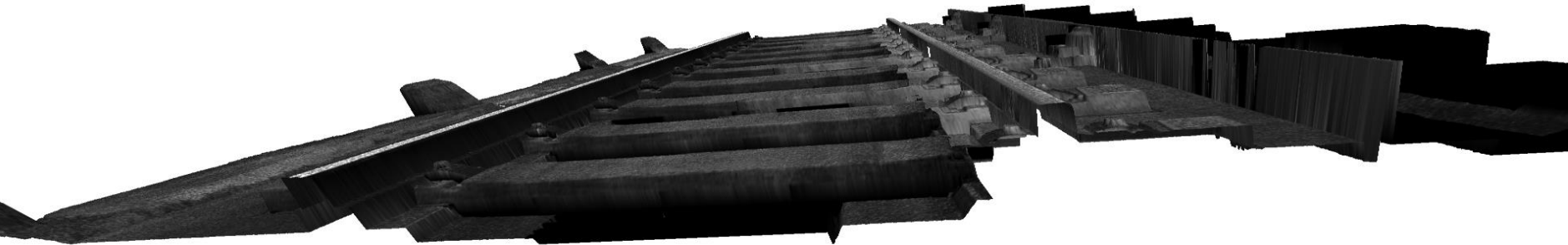
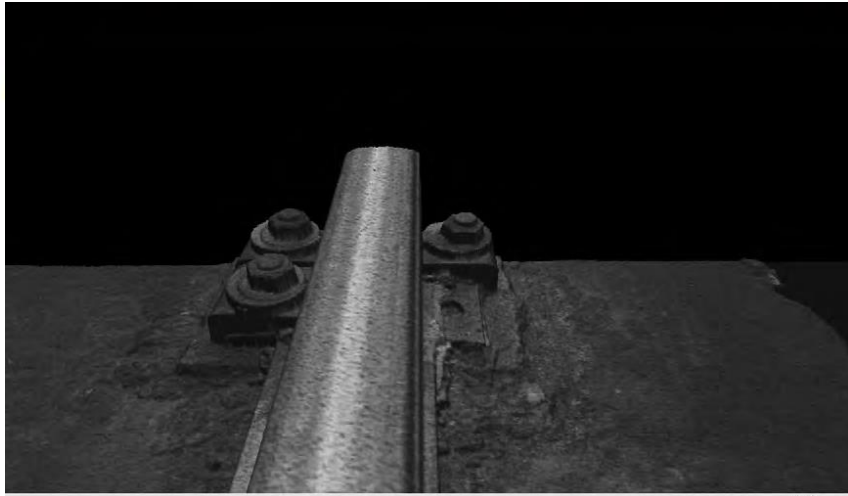


Concrete



Porous





Pavemetrics

APPLICATION: Tunnels



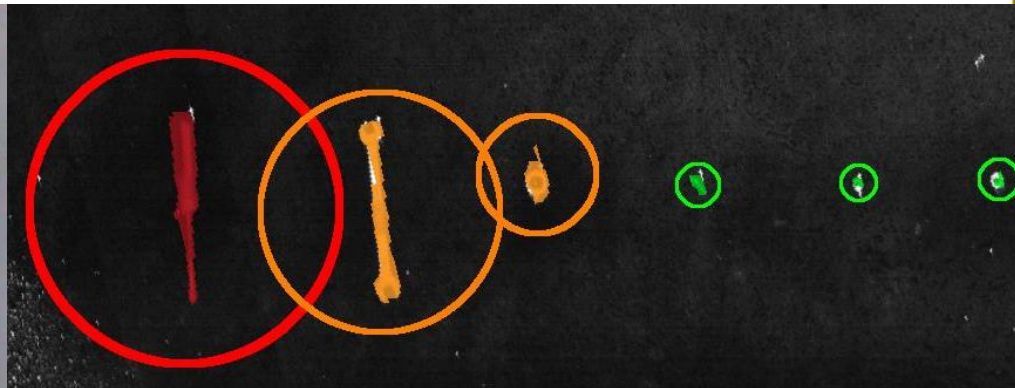
Application: Airports - FOD



Google Earth interface showing an LCM5 survey area. The popup window displays the following FOD information:

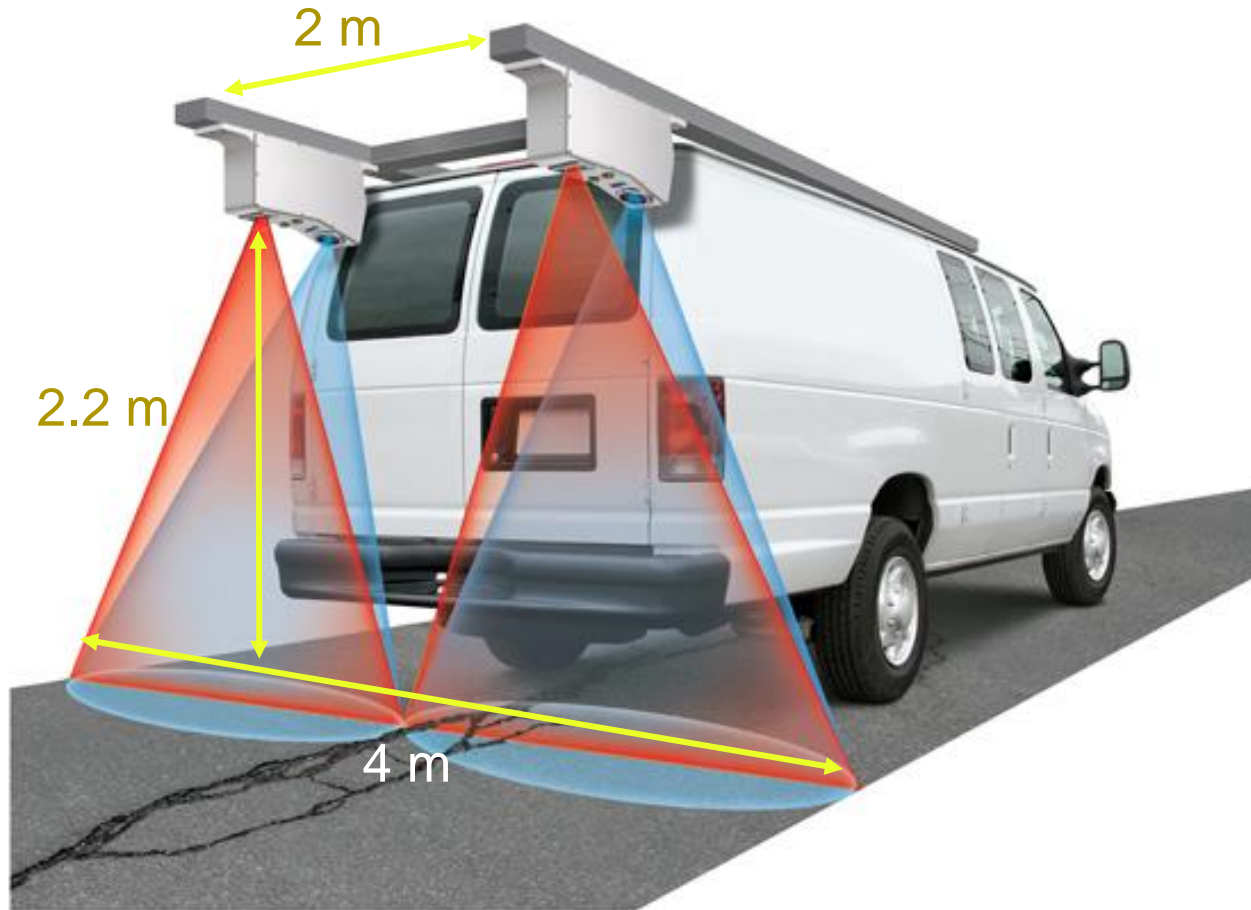
FOD Information:	
Area (mm ²)	51.00
Maximum Height (mm)	39.10
Average Height (mm)	12.40
GPS Coordinate	Longitude: -79.603493 Latitude: 43.671040 Altitude: 166.065002
Bounding Box	MinX: 726.50 MaxX: 858.50 MinY: 702.70 MaxY: 787.20

The popup also includes a small image of the detected FOD, which is a red circular object on a grey surface. The background shows a map of an airport with various elevation points and a red triangle marker indicating the survey location.



Runways currently scanned with Pavemetrics Technology





Laser profiling (principle)

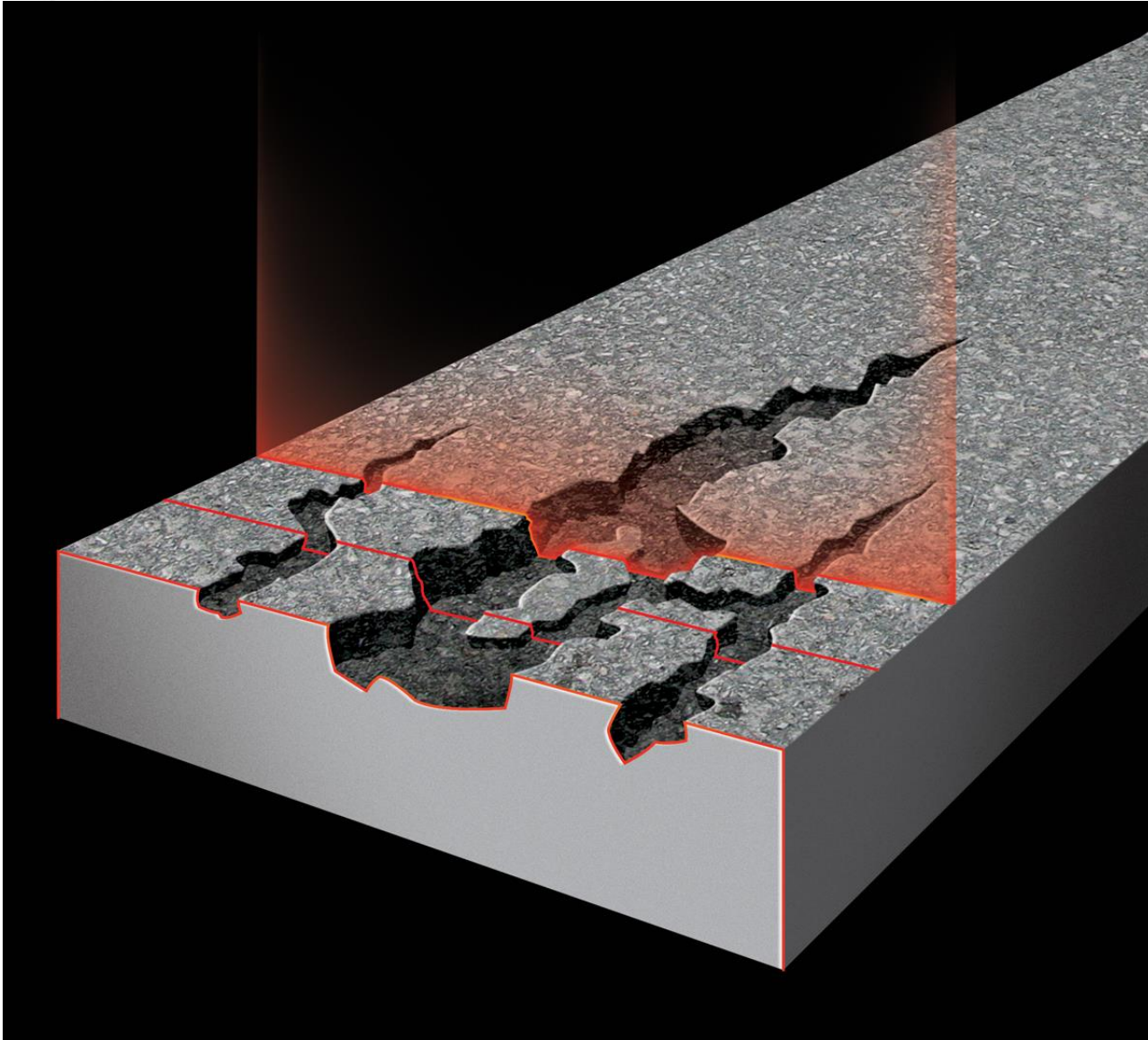
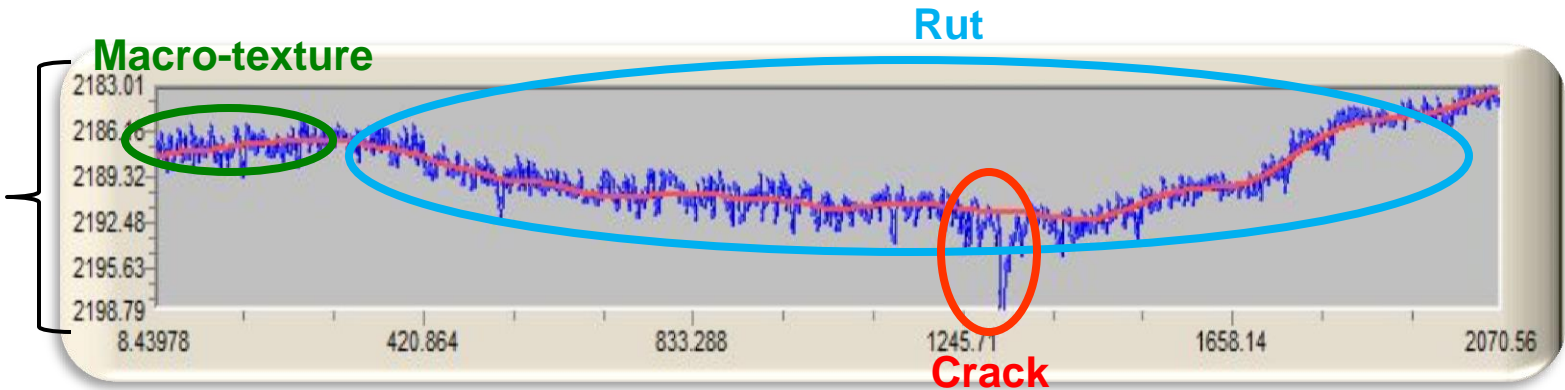
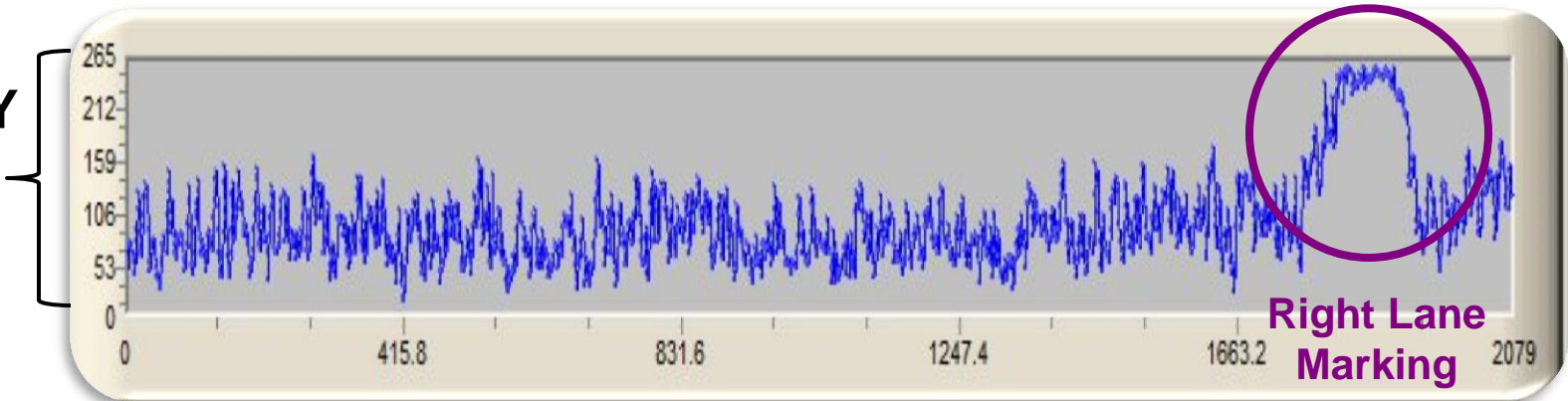


Image and Data Analysis

RANGE
Distance
between
Sensor and
ground
(in mm)



INTENSITY
Laser
intensity
(black = 0,
white = 255)



2D Technology

- One “data stream” – digital image
- Identify distresses based on how they “look”
- Problem: things are not always as they appear
- Labor intensive, rater subjectivity, false positives/negatives...



<http://www.julianbeever.net/>

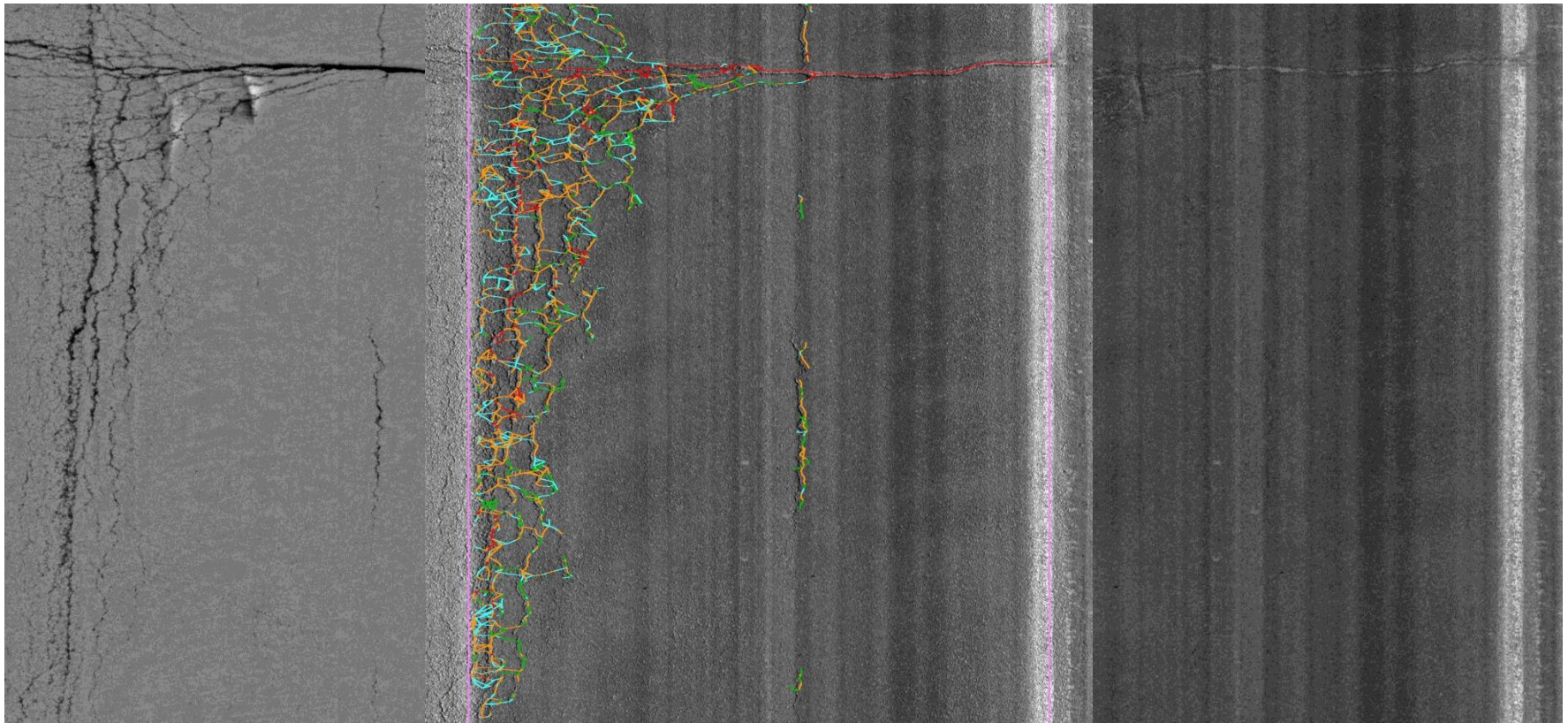
3D Technology

- Two “data streams”
- Can analyze distresses based on how they “look” AND their shape
- Actual width and depth of distress
- Objective, repeatable, far less labor, better data

The screenshot displays the Pavemetrics software interface. The main window is titled "inspect" and shows a file path: "Users\JFHebert\Documents\LCMS\Data\2010-05-04 Tests around INO\9\l.cmsData_000515.fis". The interface is divided into several sections:

- Image View:** Two side-by-side grayscale images of a pavement surface with a prominent crack. A red circle highlights a specific point on the crack in the left image, with a red arrow pointing to the profile graph below.
- Control Panels:** Below the images are two identical control panels for "Data to display" (Intensity, Range, Rectified Range) and "Z Range" (Auto, Min, Max). The left panel has a Z Range of 2182.5 to 2212.5, and the right panel has a Z Range of 2166.27 to 2206.27.
- Profile Graph:** A line graph at the bottom shows the profile of the pavement surface. The Y-axis represents height (ranging from 2191.9 to 2203.78) and the X-axis represents distance in pixels (ranging from 0 to 2079). A red circle highlights a sharp dip in the profile, corresponding to the crack location.
- Right Panel:** A vertical sidebar contains various settings and controls:
 - Open:** Current File: 516/820
 - Road Section:** Id: 515, Resolution: 5.0mm, Length: 2.0m, Distance: 1.030km, Time (h:m:s): 0:1:6.4
 - System Info:** Survey Id: 2050454015, Nb Sections: 820, Total Length: 1.640km
 - Proc Selection:** Lane Mark, Crack, Rutting, Macro Tex., Potholes (Sensitivity: 1)
 - Result Display:** Lane Mark, Crack, Potholes (View Result)
 - Proc. Multiple:** Start, Stop, Status, Done, Cur Sec. Id: 515, Progress: 1/1, Analysis Time: 1632.3ms, Errors: None (View Errors), Quit
 - Profile Disp.:** Intensity, Range, Rectif. Rng, CCD, 193 Y, Auto Scale

Understanding 3D Imaging

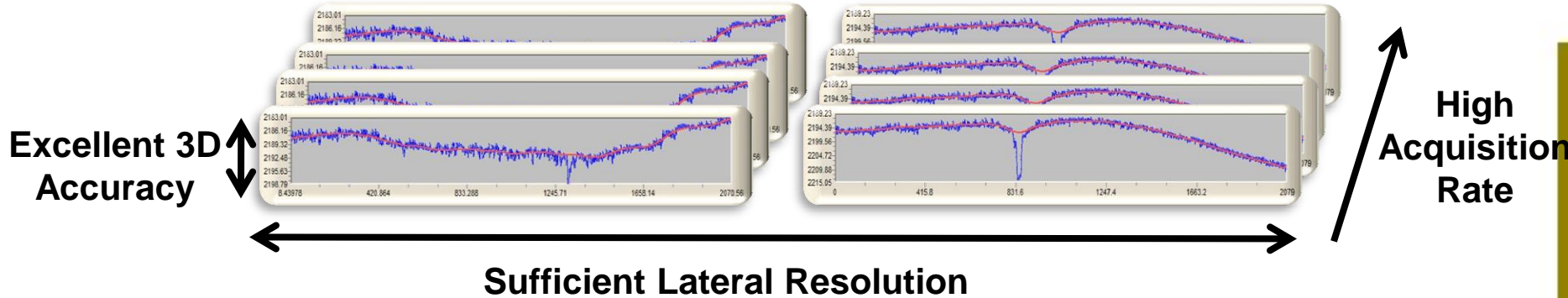


Range

Merged

Intensity

LCMS - Specifications

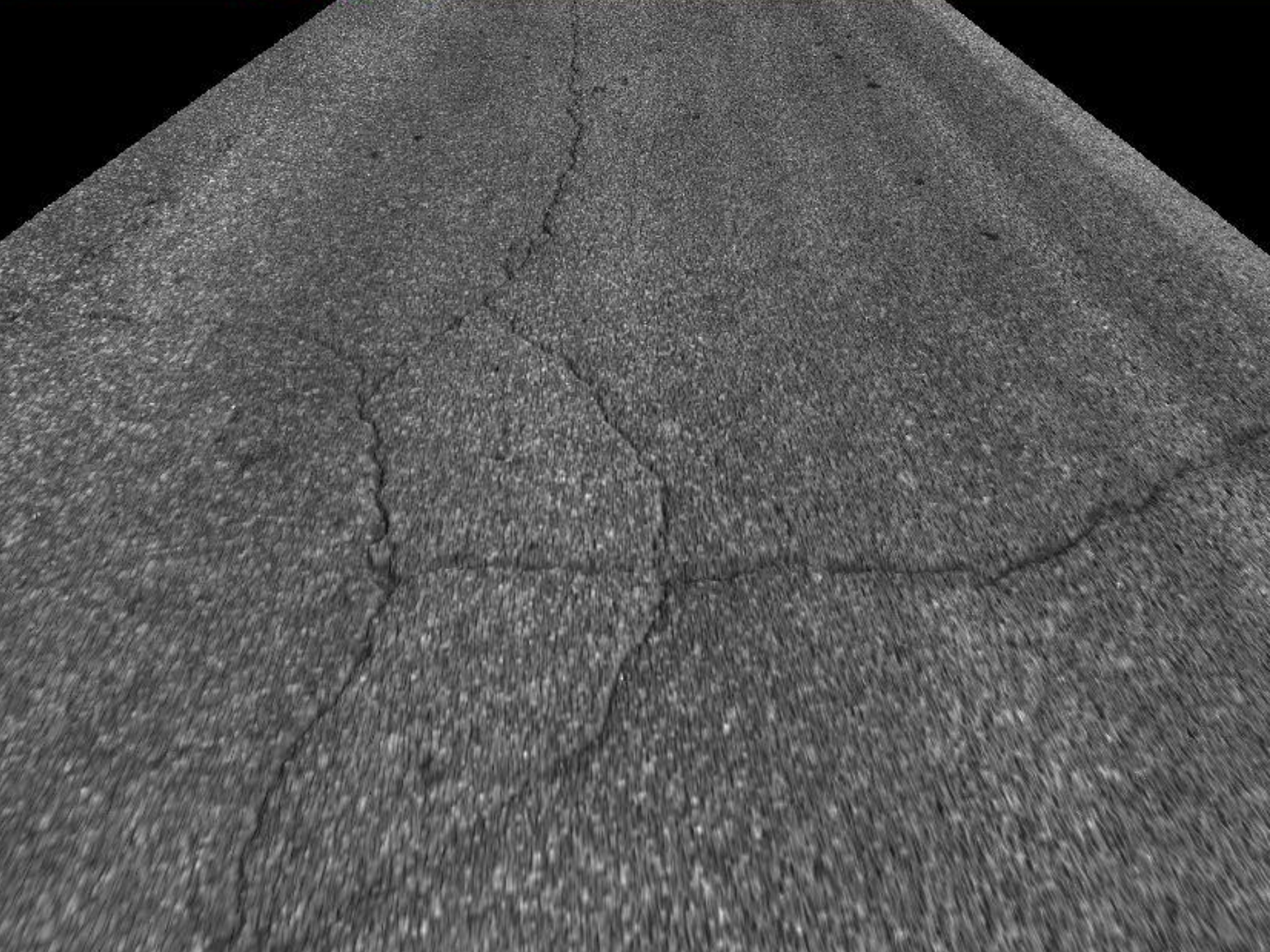


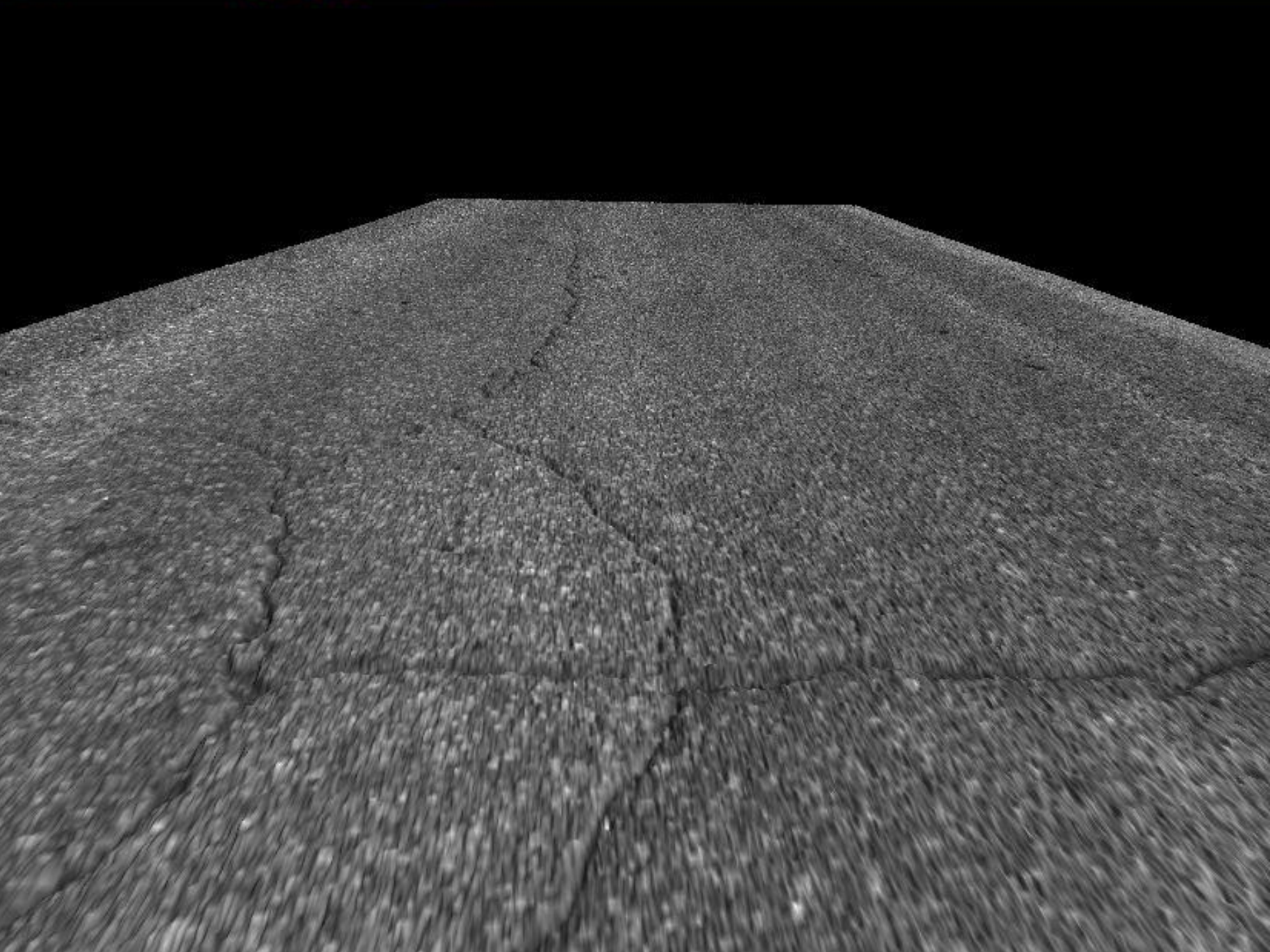
LCMS Specifications


Acquisition Rate	5,600-11,200 profiles/s
Range Accuracy	0.5mm
Lateral Resolution	1mm (FOV = 4m)
Number of points/s	45 MHz (3D and 2D)





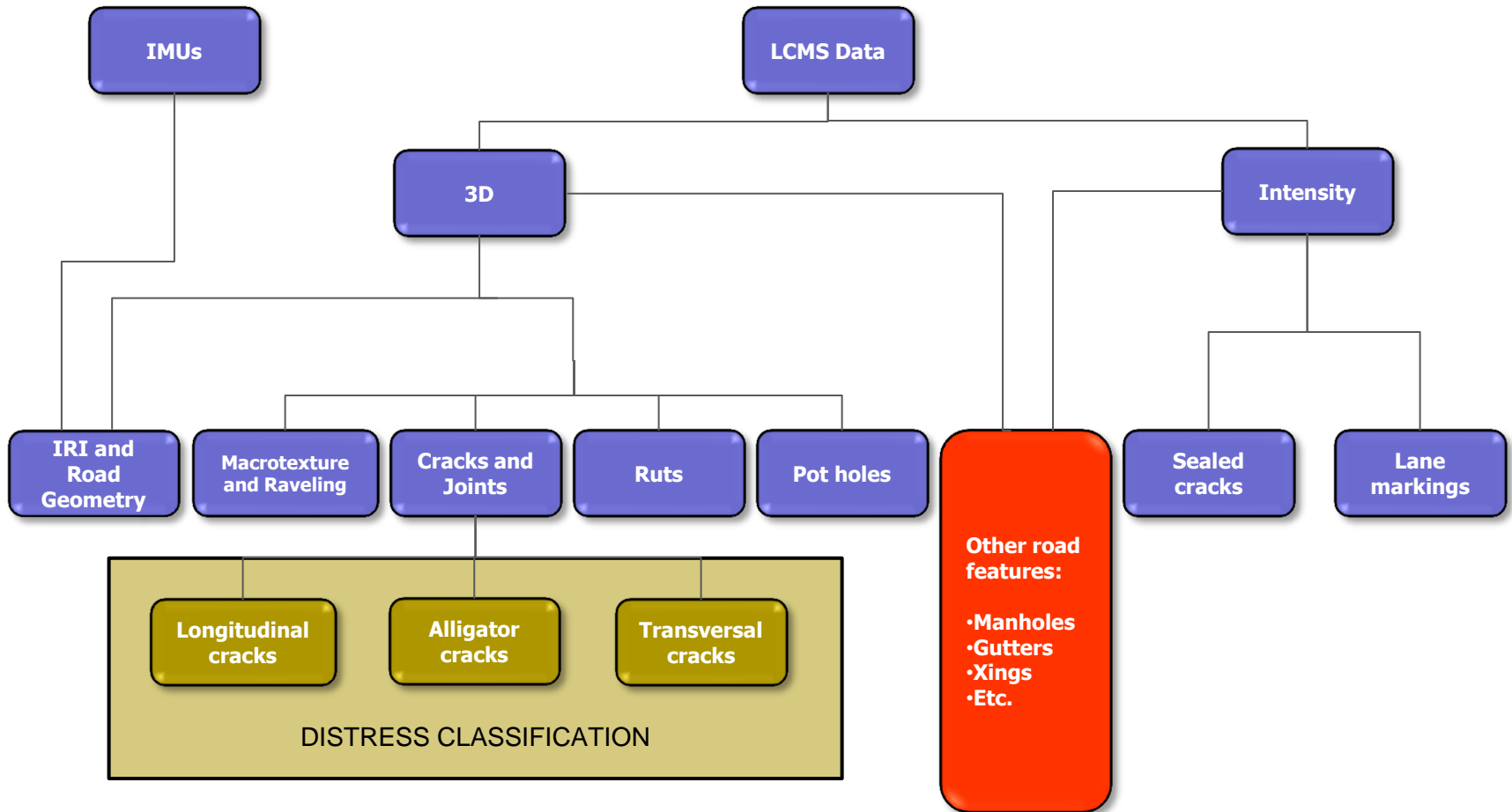






**SOFTWARE
IS
KEY!**

LCMS Data Processing Tree



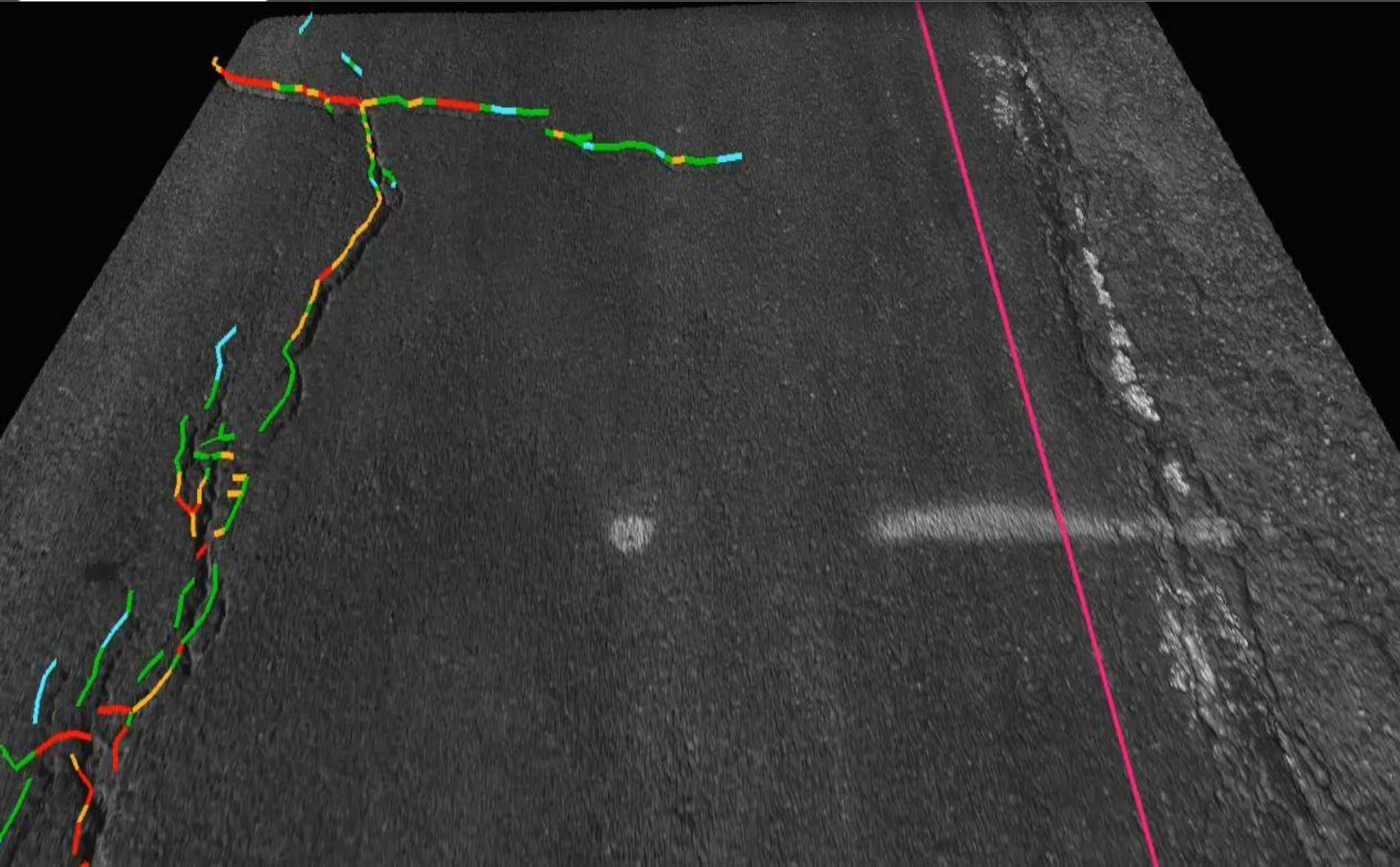
Pavemetrics

Crack Detection



Pavemetrics

Edge Dropoff Detection



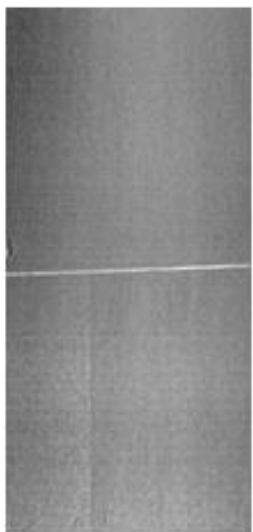
LCMS crack detection tests



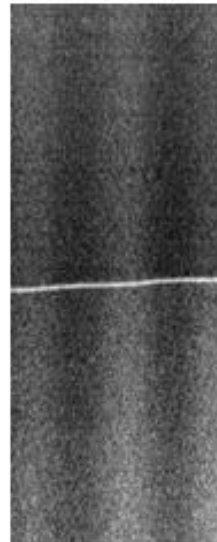
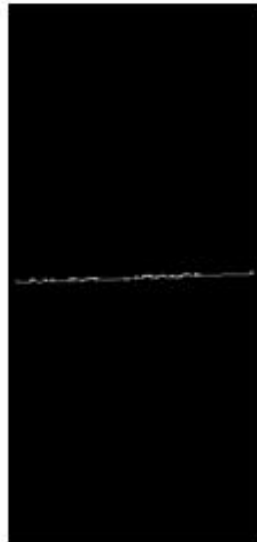
(a) 1mm (daytime)



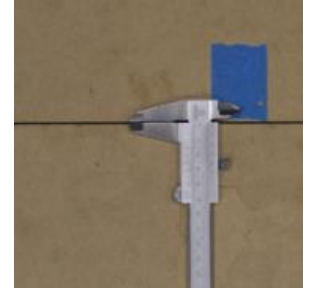
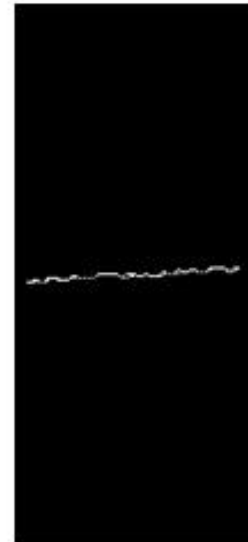
(b) 1mm (night)



(c) 2mm (daytime)

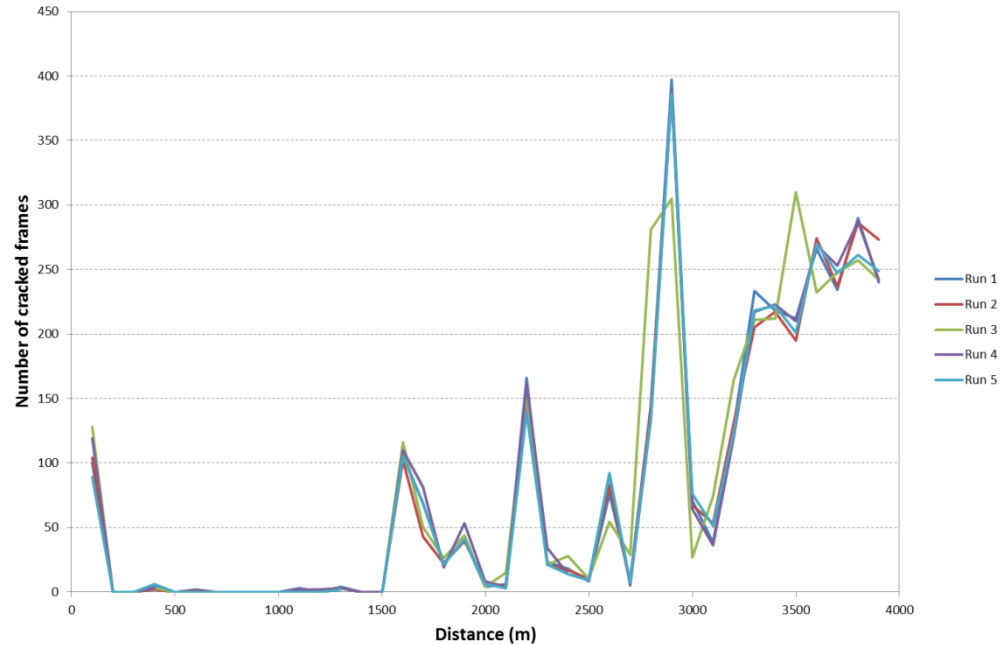
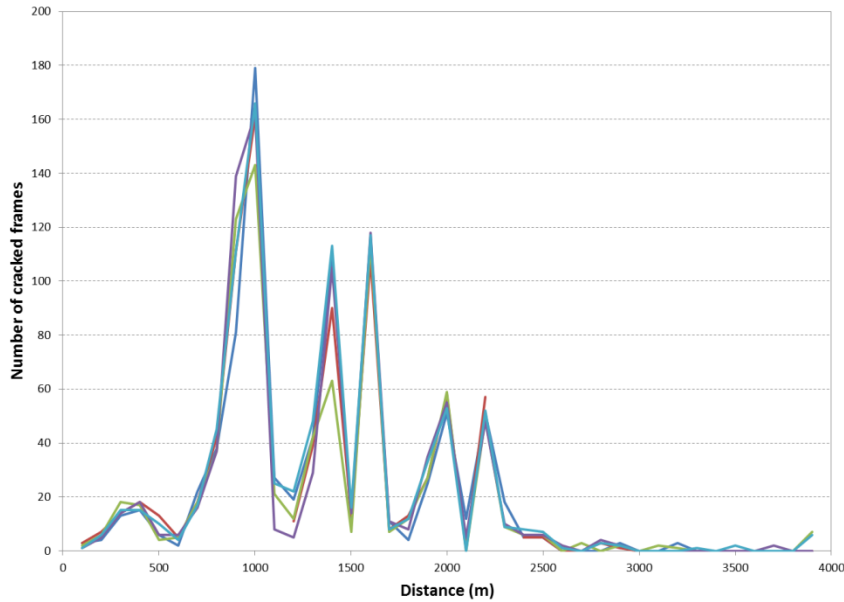


(d) 2mm (night)

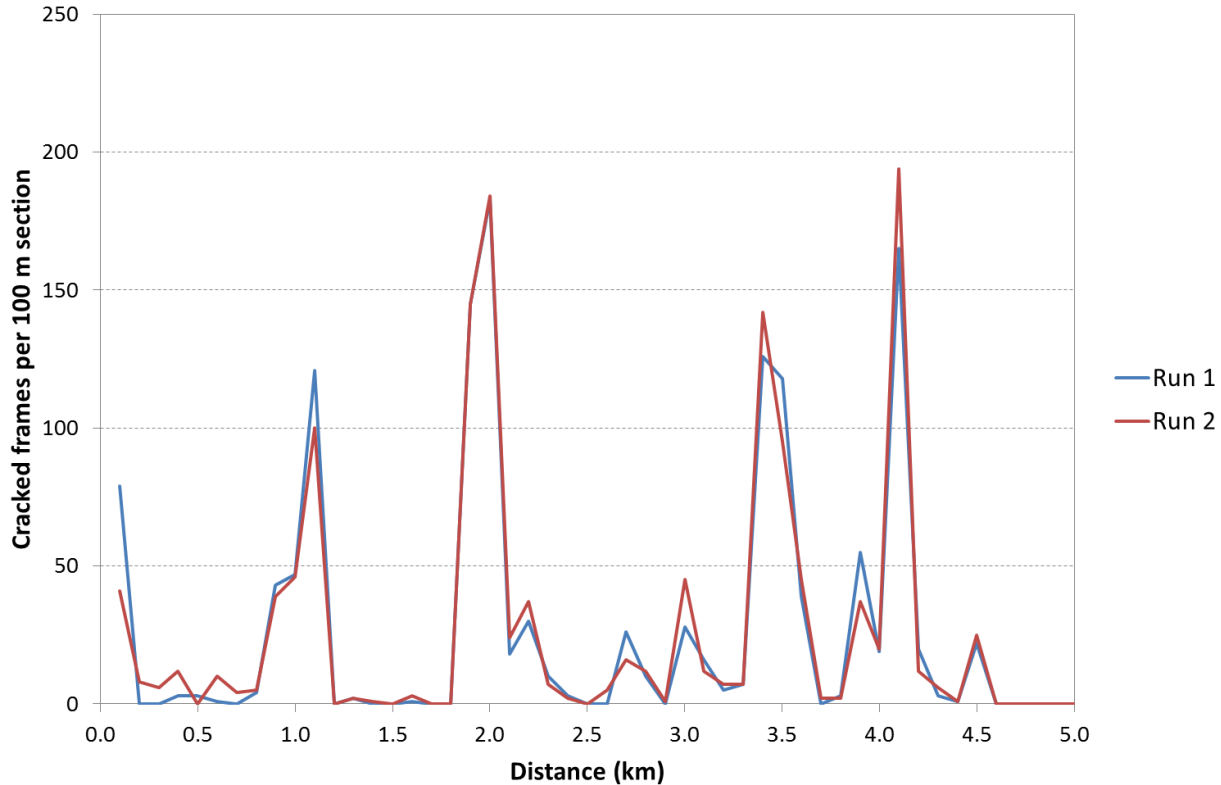


LCMS repeatability DGA test site – ARRB - Australia

		Run 1	Run 2	Run 3	Run 4	Run 5
Eastbound	r^2	0.968	0.997	0.972	0.983	0.992
Westbound	r^2	0.994	0.992	0.929	0.992	0.992



LCMS repeatability on a section of sprayed seal surface ($r^2 = 0.96$)



Pavemetrics

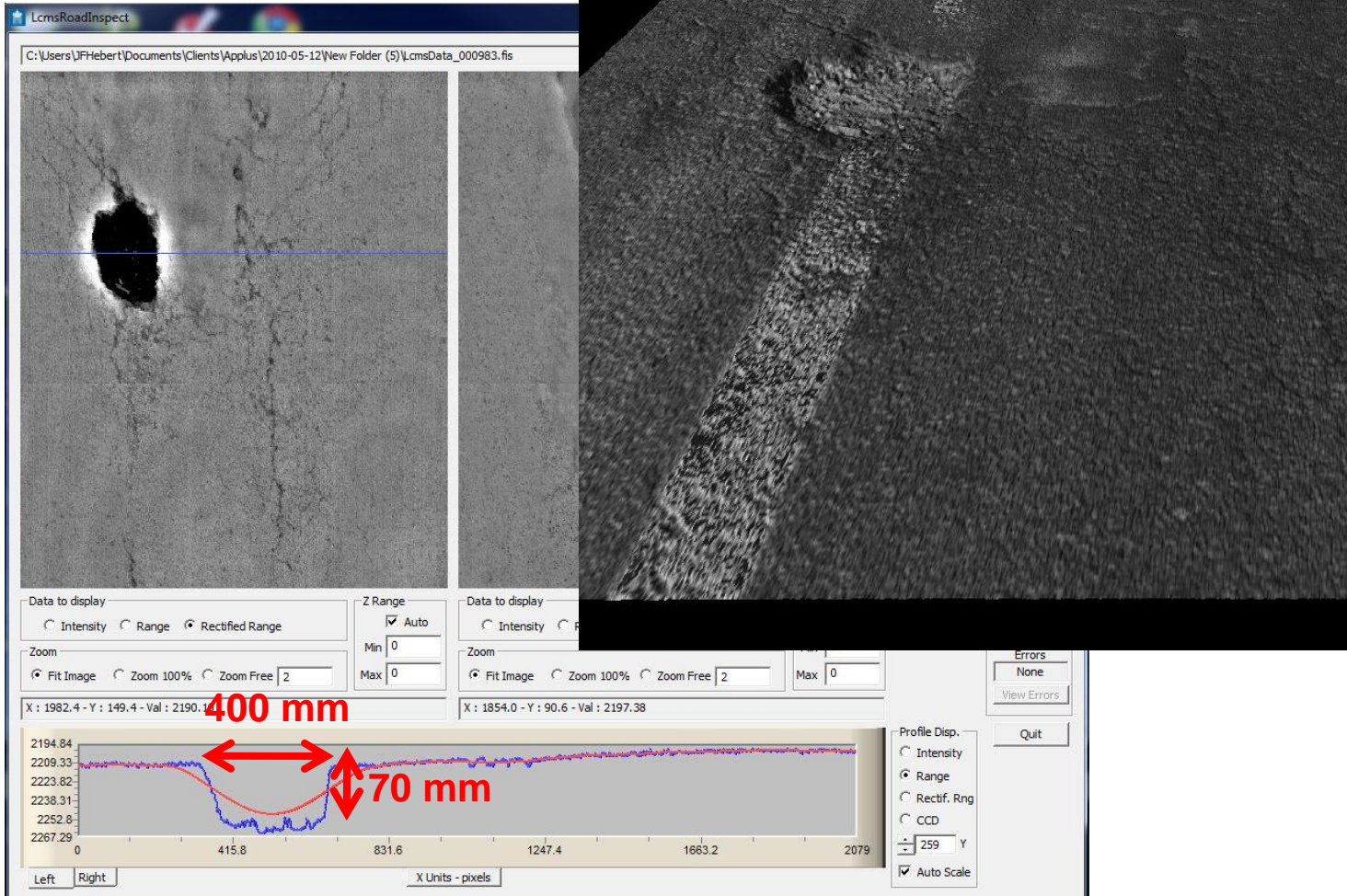
Network level testing 6000mi Summer 2008



Results – network level visual evaluation

District #	Total (sections)	Results (manual classification)							
		Number of images (10m sections)				Proportion (%)			
		Good	Average	Bad	NA	Good	Average	Bad	NA
84	35288	34144	310	144	690	96,8	0,9	0,4	2,0
85	4243	4101	53	51	38	96,7	1,2	1,2	0,9
86	147903	144040	516	1520	1827	97,4	0,3	1,0	1,2
87	149926	138453	1170	5728	4575	92,3	0,8	3,8	3,1
88	189097	183010	1064	2002	3021	96,8	0,6	1,1	1,6
89	125003	121835	442	2015	711	97,5	0,4	1,6	0,6
90	123653	116930	2980	2434	1309	94,6	2,4	2,0	1,1
91 & 92	215513	213142	197	956	1218	98,9	0,1	0,4	0,6
Total	990626	955655	6732	14850	13389	96,5	0,7	1,5	1,4

Pothole Detection



- Display
- Fit Profiles
 - Markings
 - RUTs
 - Intensity
 - 3-Point Simulation
 - 5-Point Simulation

StraightEdge

Gage Width: mm.
[19 mm, 75 mm]

Length: mm.
[1730 mm, INF]

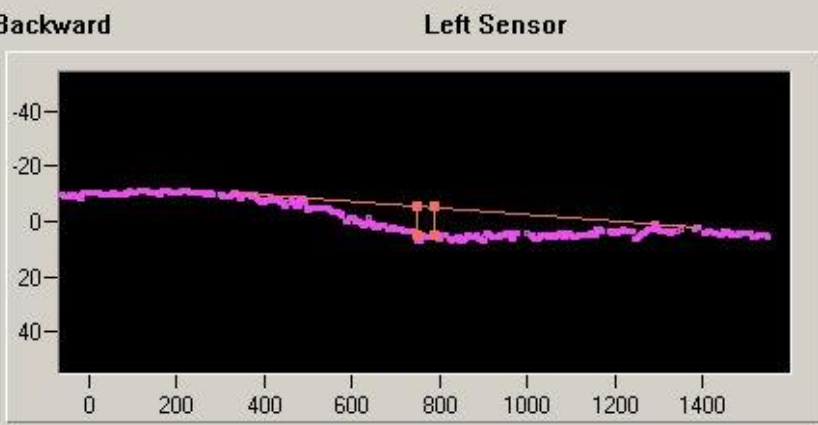
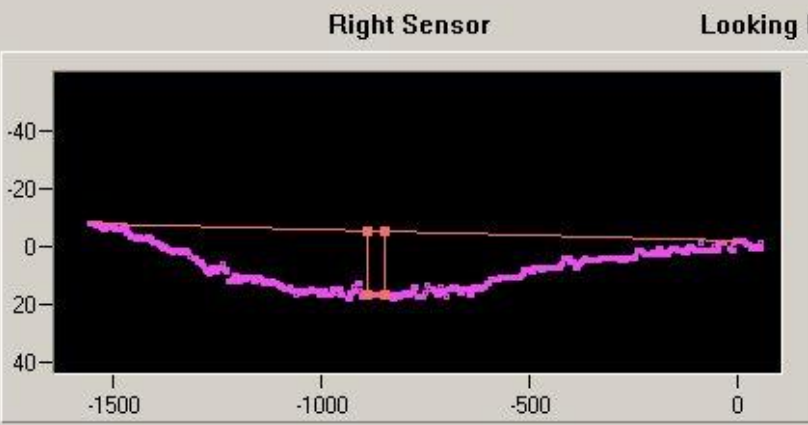
Sensors Spacing

Wheel Path: mm.
[500 mm, 1250 mm]

Outside: mm.
[1251 mm, 2000 mm]

Status: The Sensor class returned : eNO_ERROR

Status: The Sensor class returned : eNO_ERROR



LRMS Algorithms

Depth: mm.

Width: mm.

C-Sec: mm².

Multi-Point Systems

Depth:

LRMS Algorithms

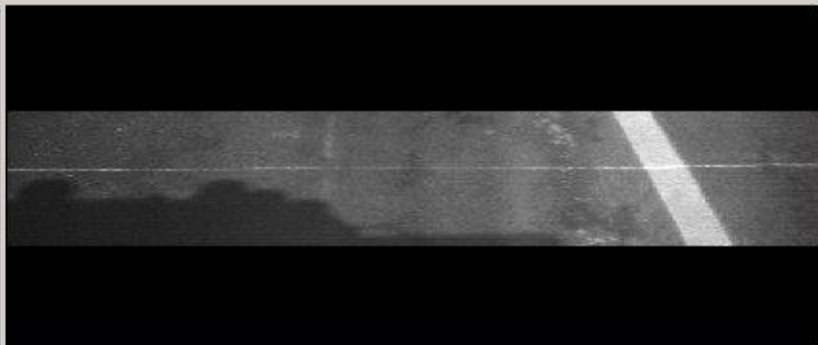
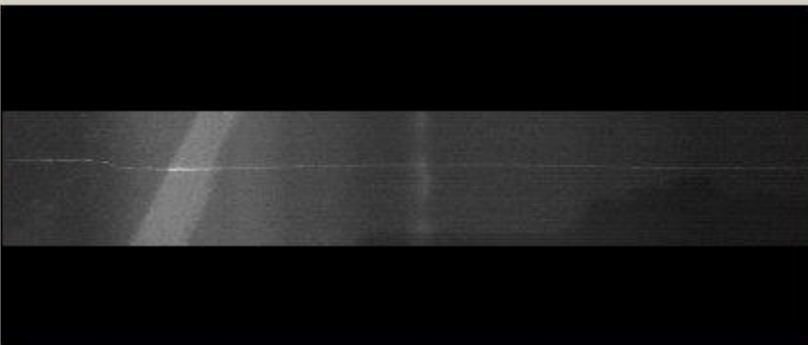
Depth: mm.

Width: mm.

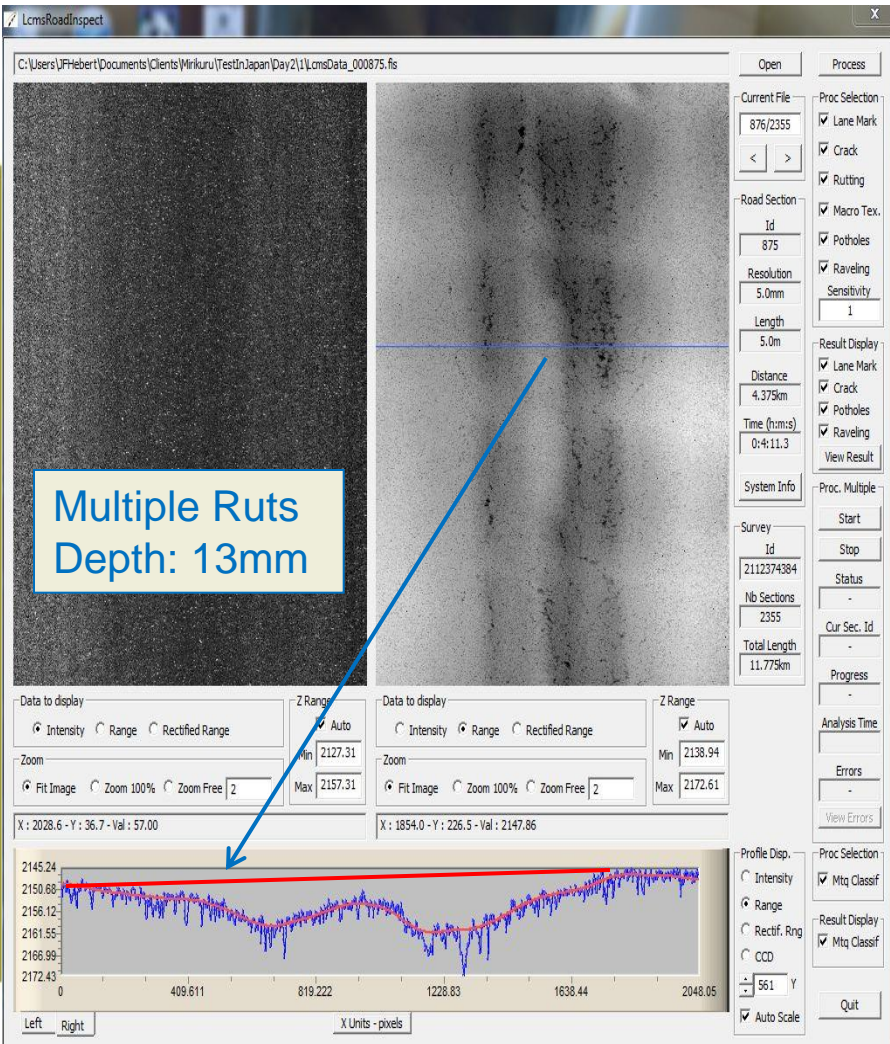
C-Sec: mm².

Multi-Point Systems

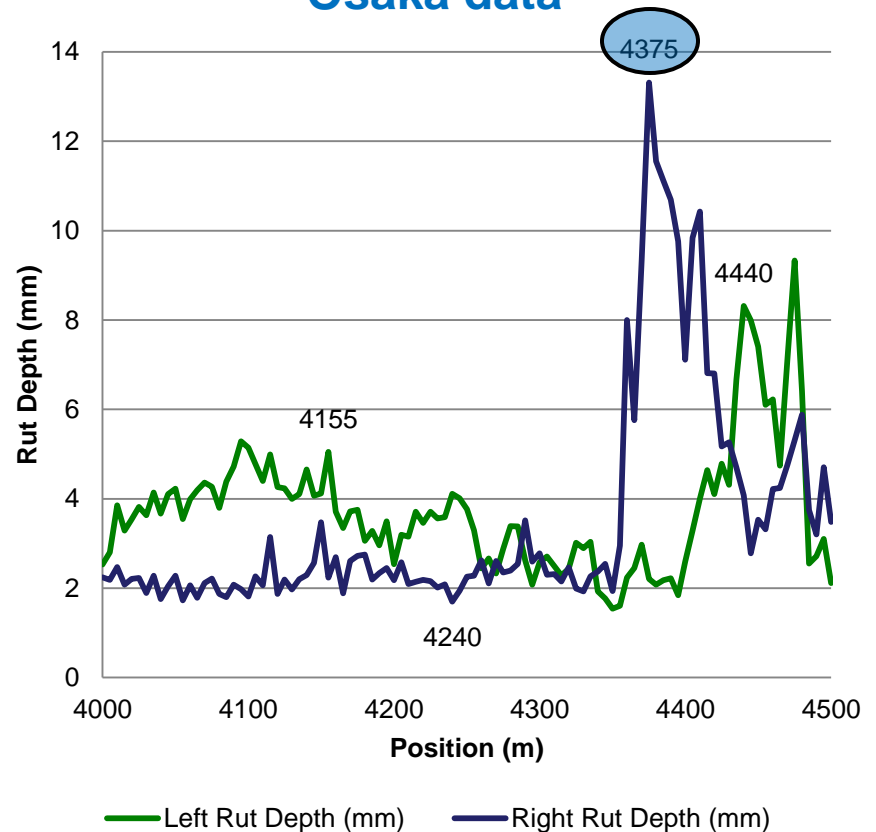
Depth:



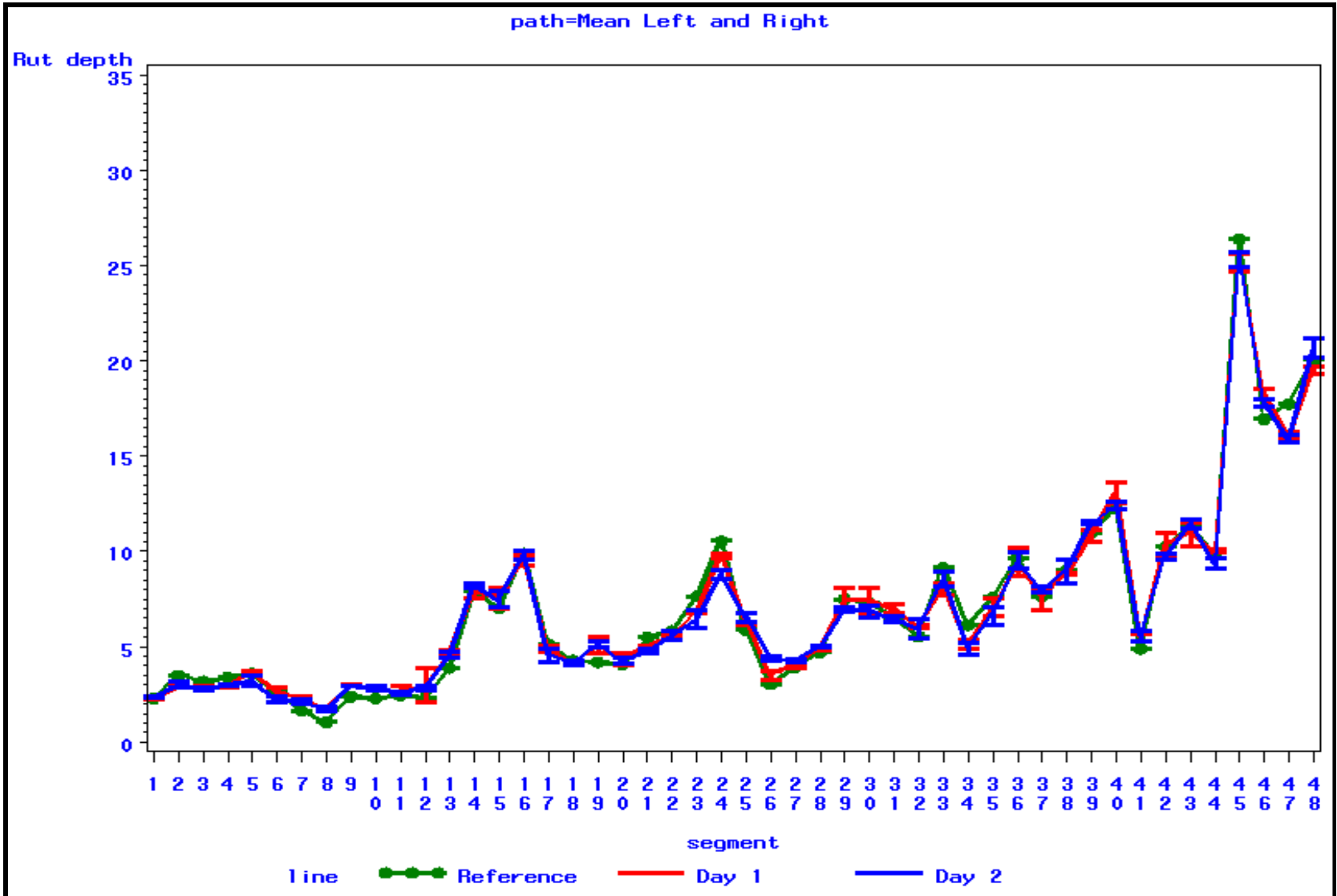
Rutting (depth, width, type)



Rut Depth (per road section) between 4.0km and 4.5km for Osaka data



MTQ validation – 100 m intervals (48 sections)





Rough Texture

Smooth Texture

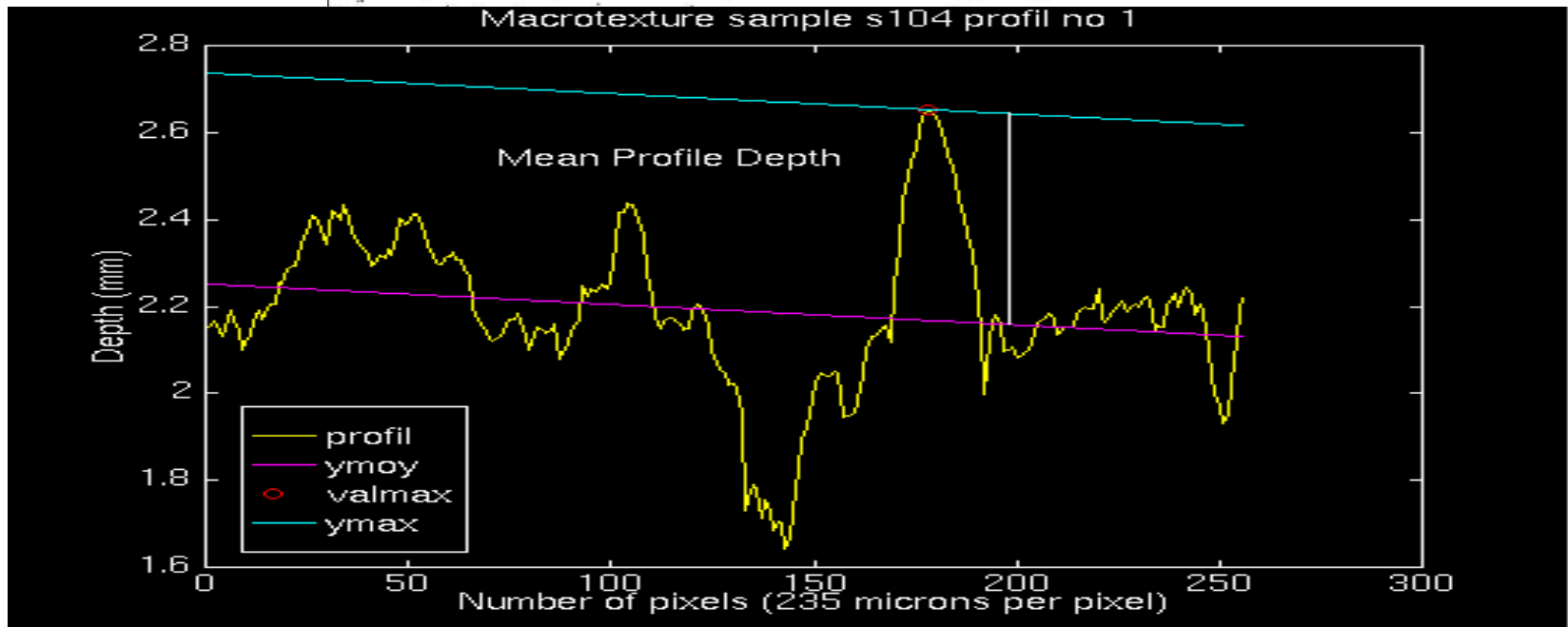
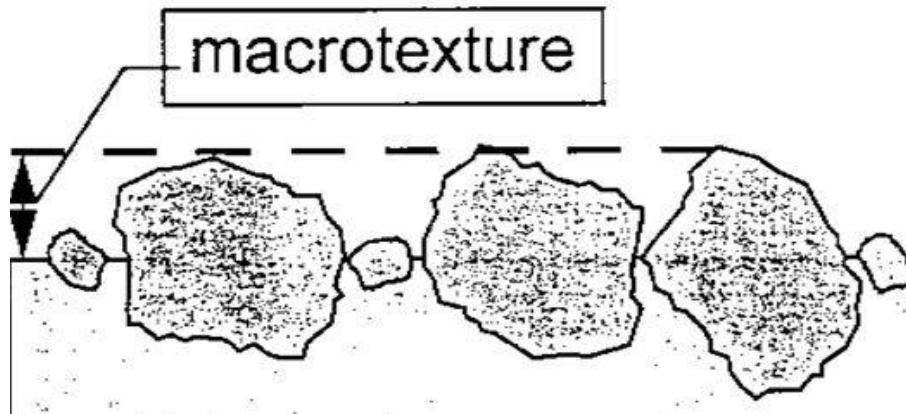
Macrotexture : Mean Profile Depth (ASTM E1845-01)

Specifications:

- 32kHz or 64kHz laser
- 1mm point spacing (minimum)
- 0.05 mm vertical resolution
- Low pass filtering 2.5mm features removed. 5mm+ features kept intact.

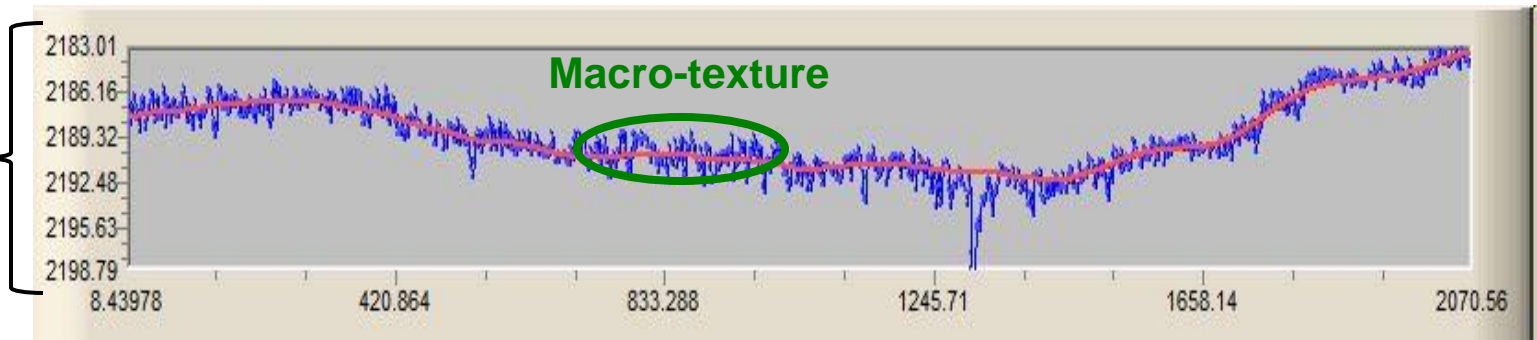


Macrotexture : Mean Profile Depth (ASTM E1845-01)

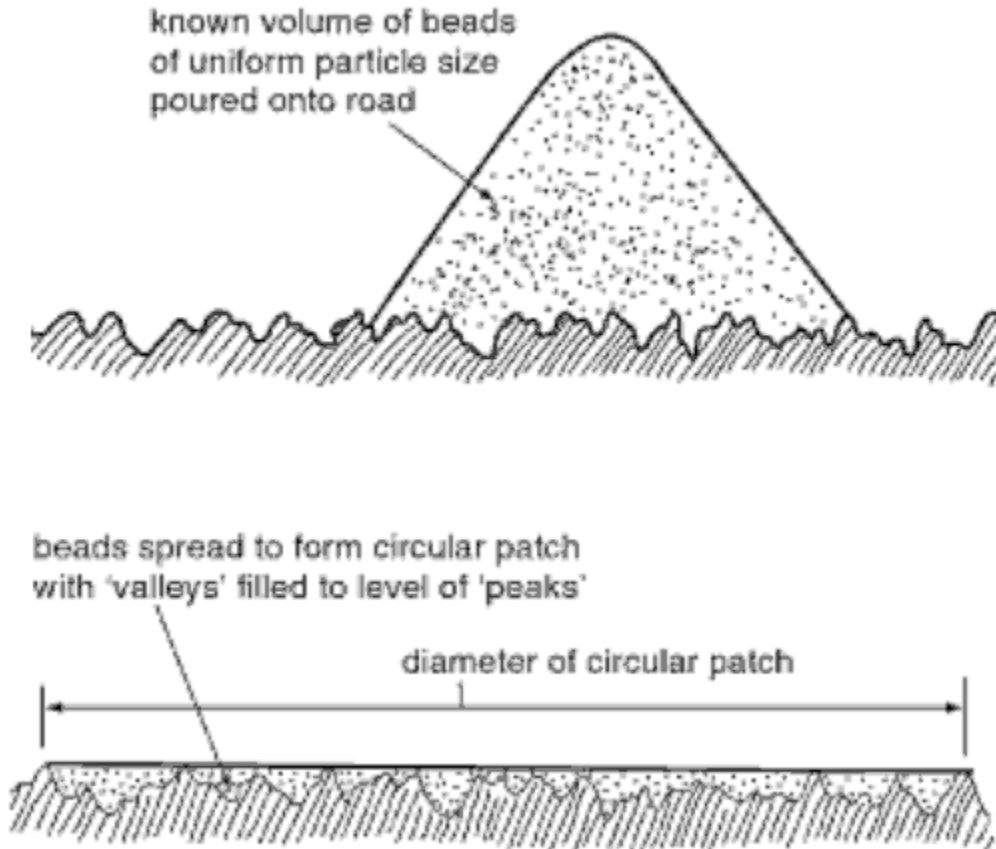


Single Road Profile (2 meter)

Distance
between Sensor
and ground
(in mm)

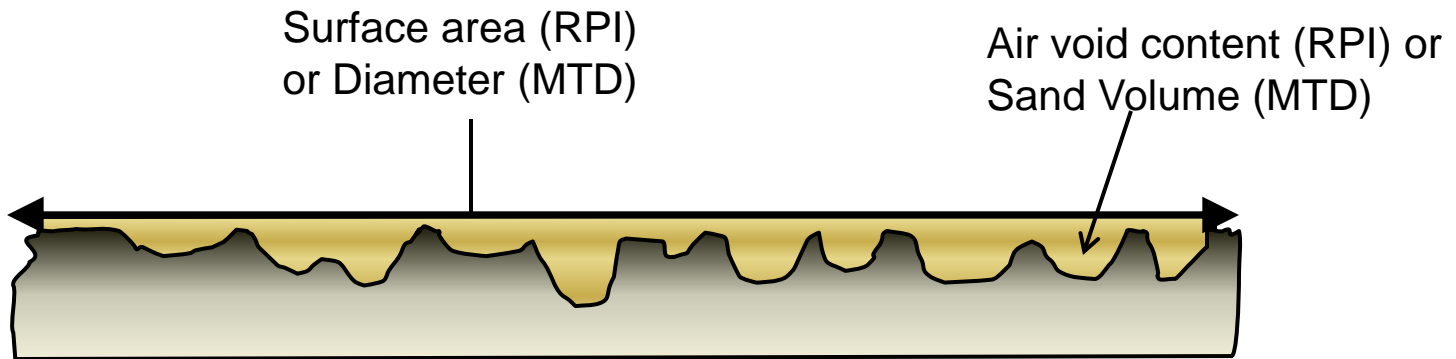


Macrotexture : Sand patch method (MTD) (ASTM E965)



Macrotexture – RPI Digital Sand Patch Method

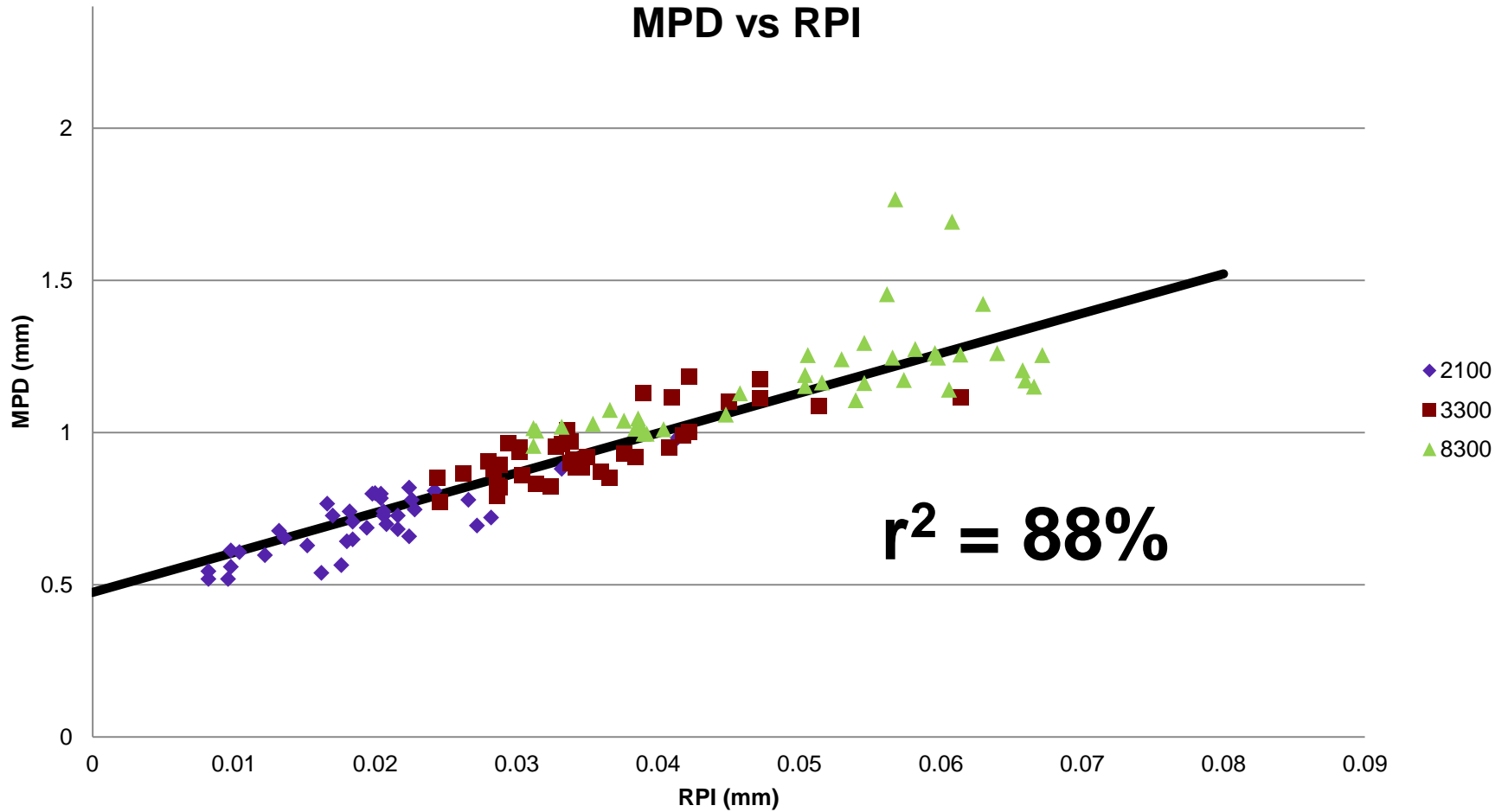
RPI - Road Porosity Index = (Volume under the surface – Ravelling - Cracks) divided by a surface area



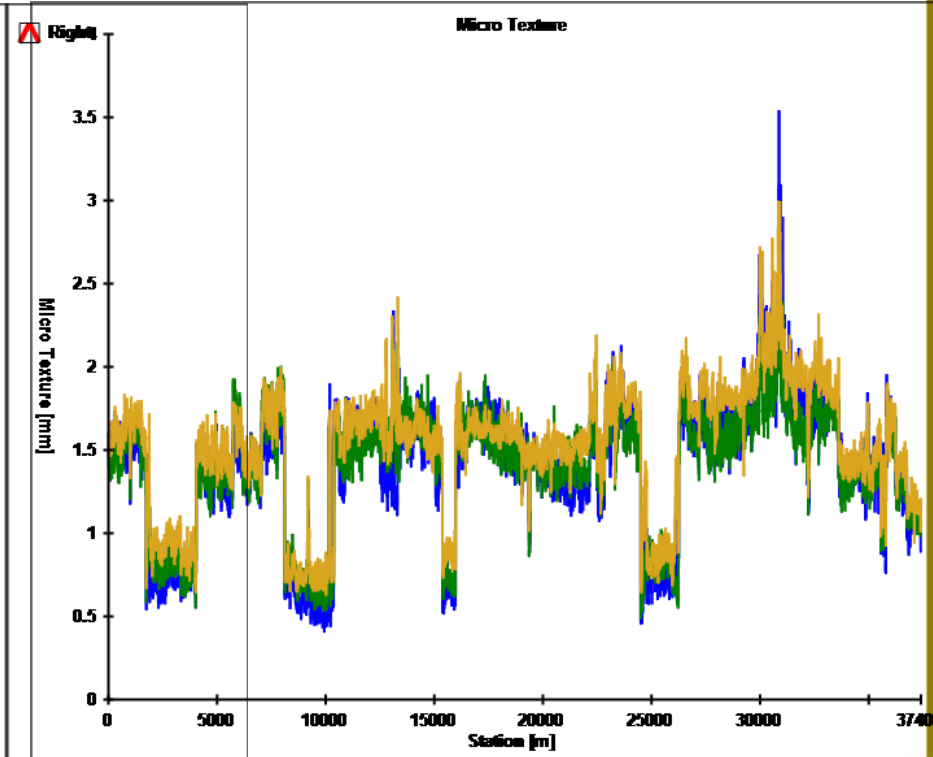
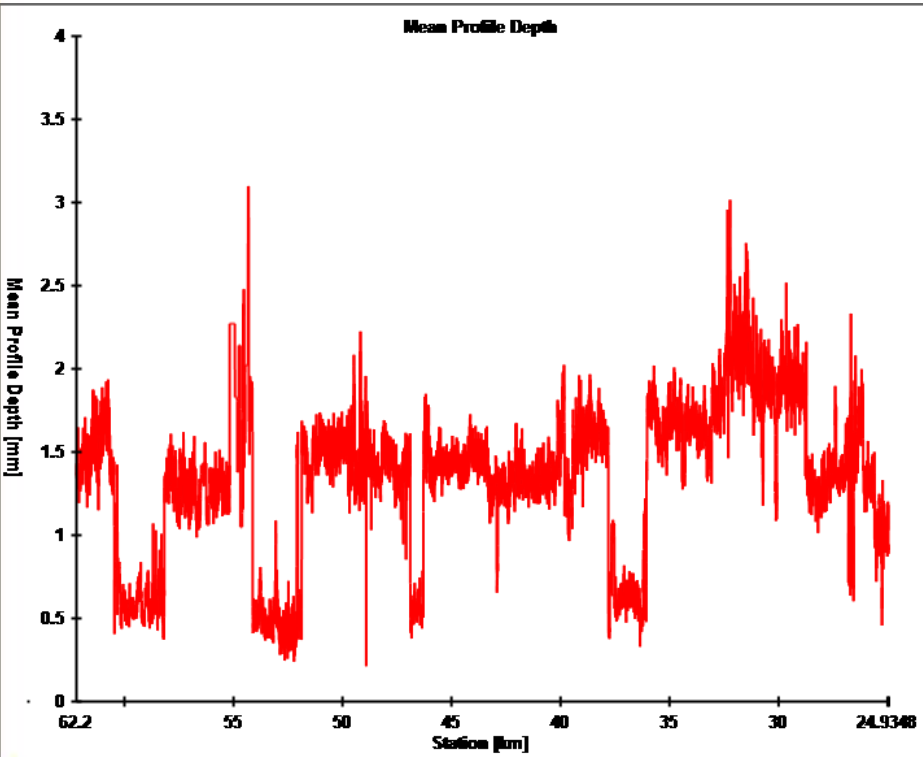
$$RPI = \frac{Vol_{air\ void} - Vol_{pothole} - Vol_{cracks}}{Area_{Total}}$$

Macrotexture – Correlation between MPD and RPI

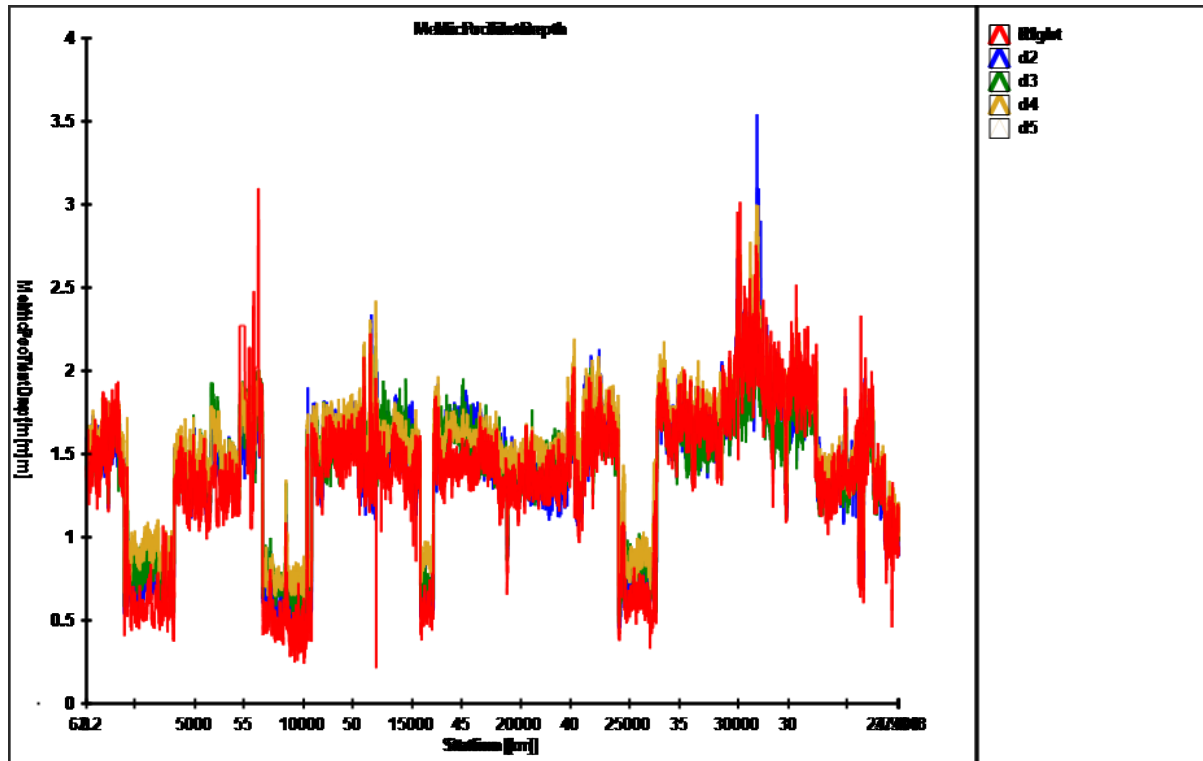
MPD vs RPI



LCMS vs 64 KHz laser

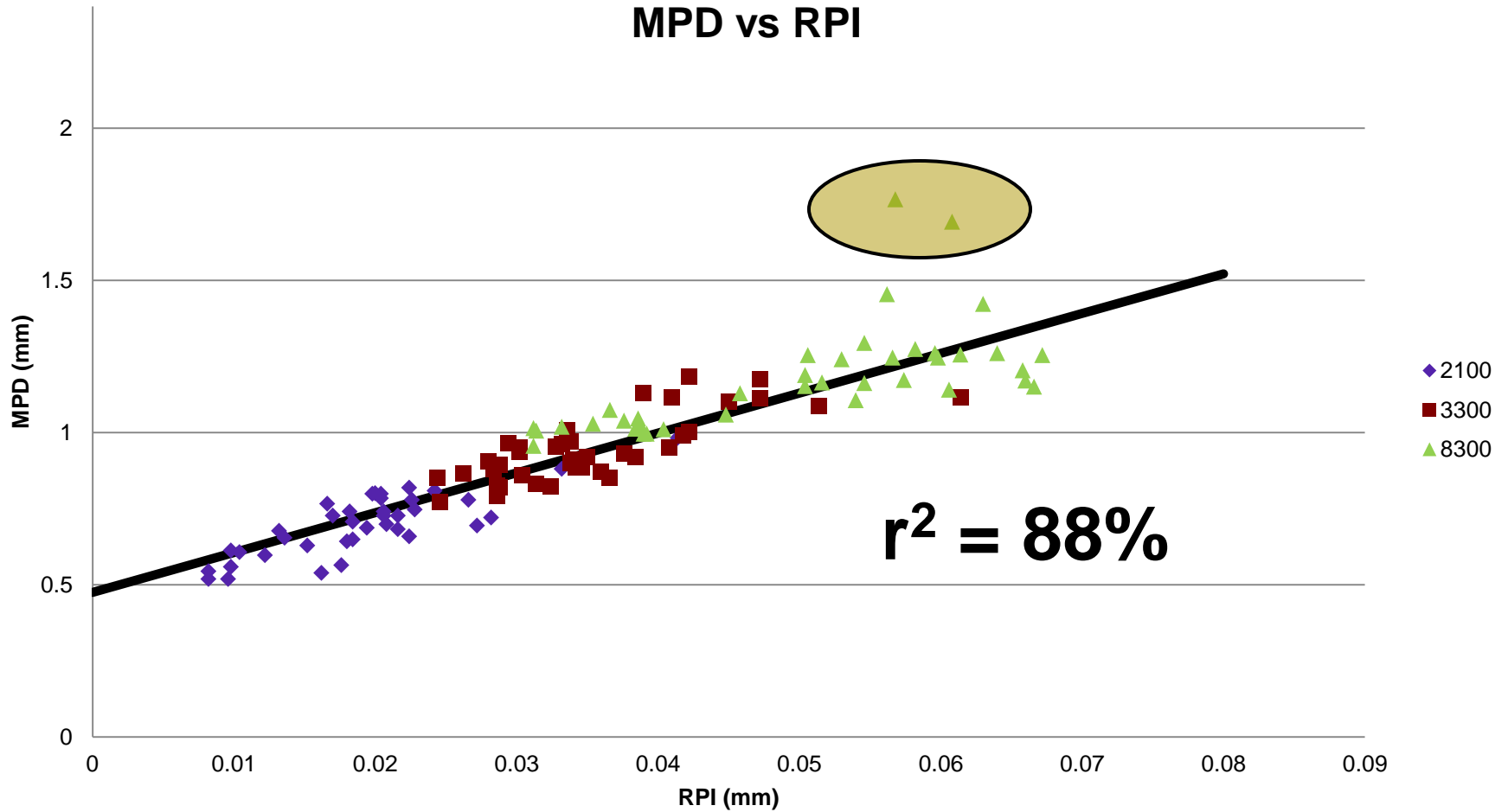


LCMS vs 64 KHz laser

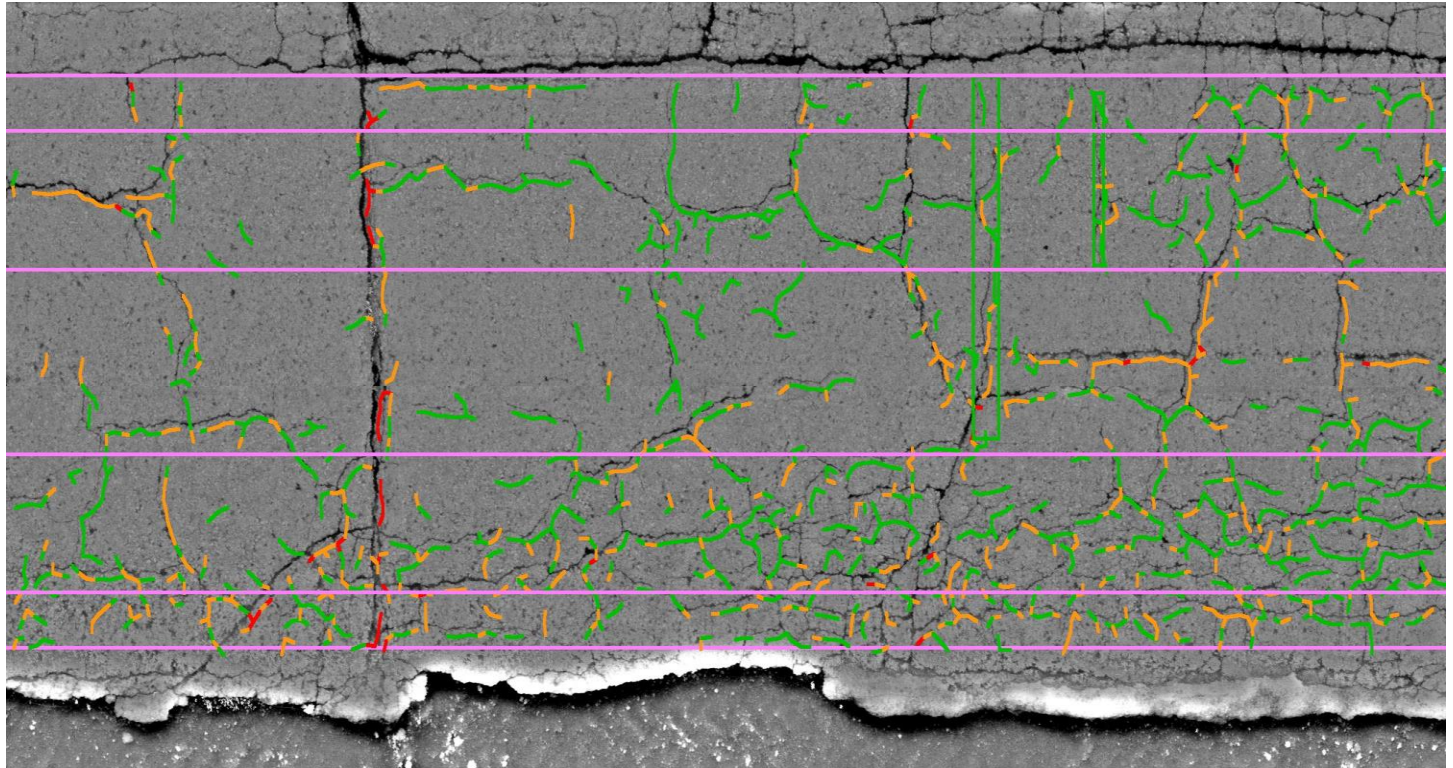


Macrotexture – Correlation between MPD and RPI

MPD vs RPI

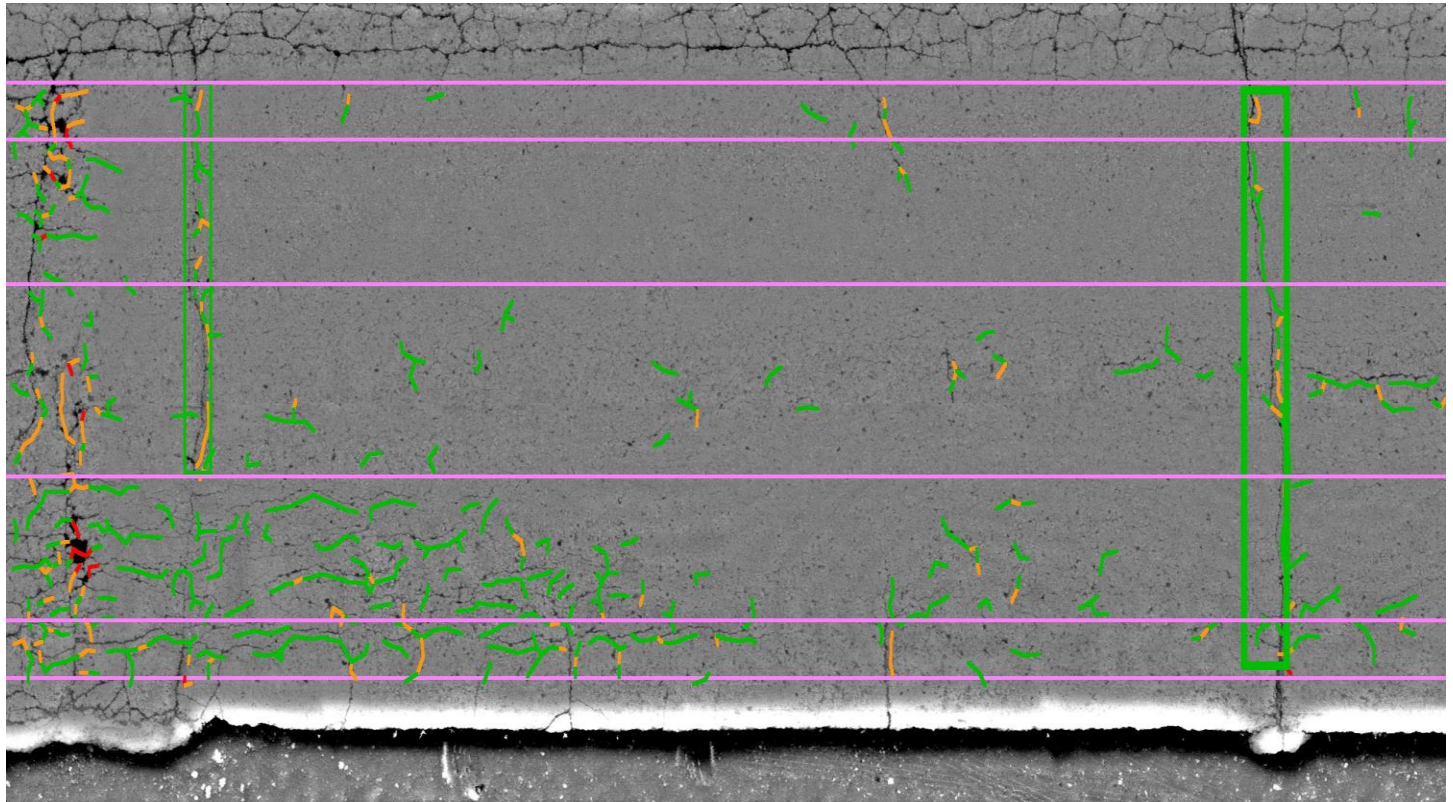


Macrotexture – Results for Section 08300



Right wheel path
(10-20m)

Macrotexture – Results for Section 08300



Right wheel path
(20-30m)

Macrotexture – LCMS Digital Sand Patch Method

Pros:

- Network survey is possible at 100kmh
- Full lane width is measured
 - 5 AASHTO bands
- Great repeatability
 - Automatic lane marking detection



Raveling tests Netherlands 2010

- Highways; 5,010 km (~20,000 lane km)
 - 10% DAC and SMA
 - 90% Porous Asphalt
- Using LCMS to detect raveling
 - Development of algorithms
 - Matching of severity levels with manual evaluators



Rijkswaterstaat vehicle

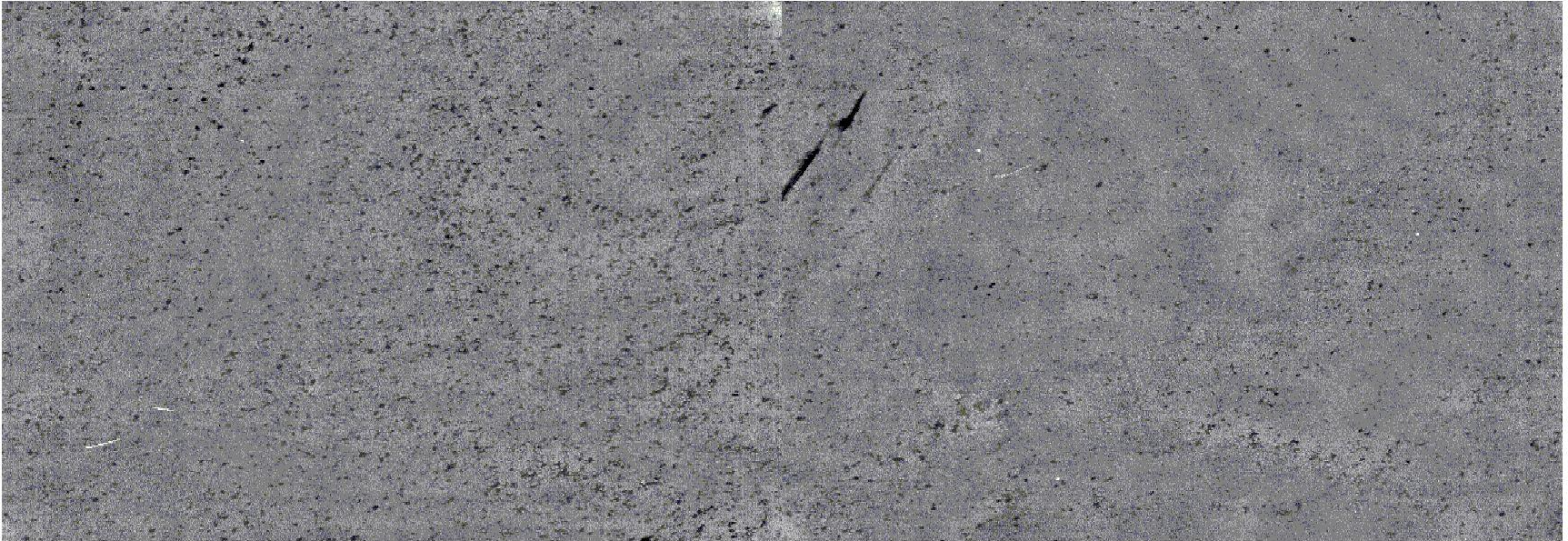


Ravelling Index - RI

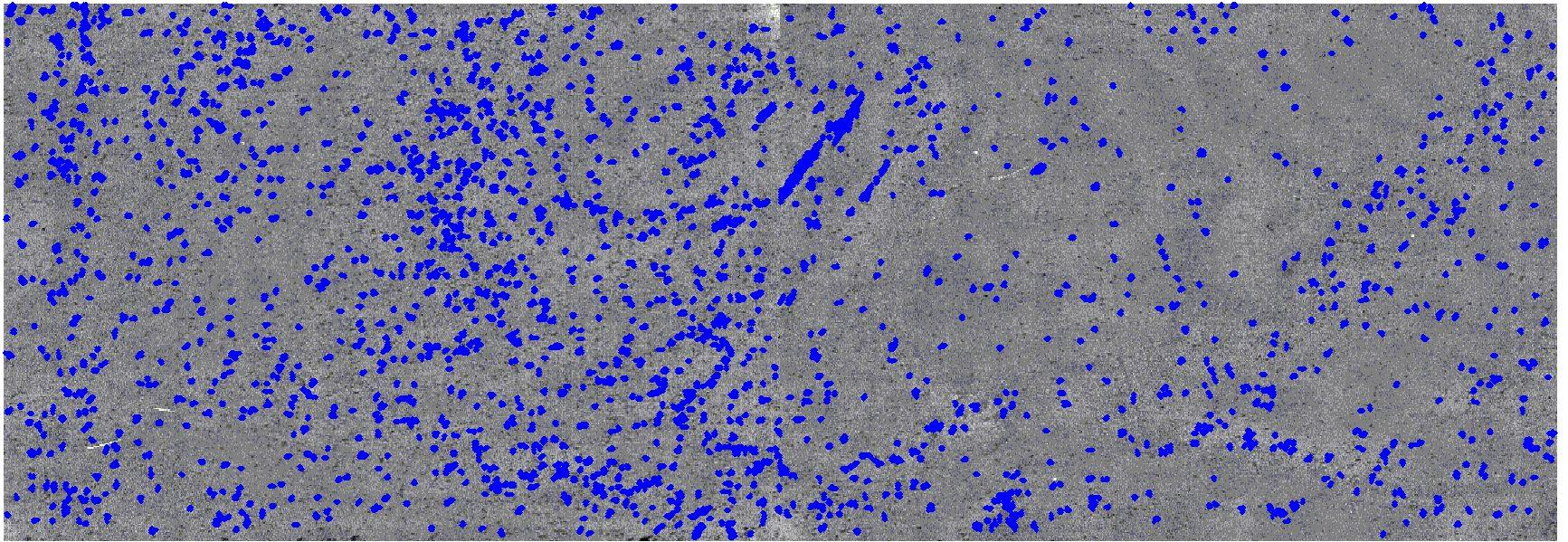
Ravelling Index (RI) = The volume of aggregate loss per surface area

$$RI = V_{\text{aggregate loss}} / A_{\text{Total}}$$

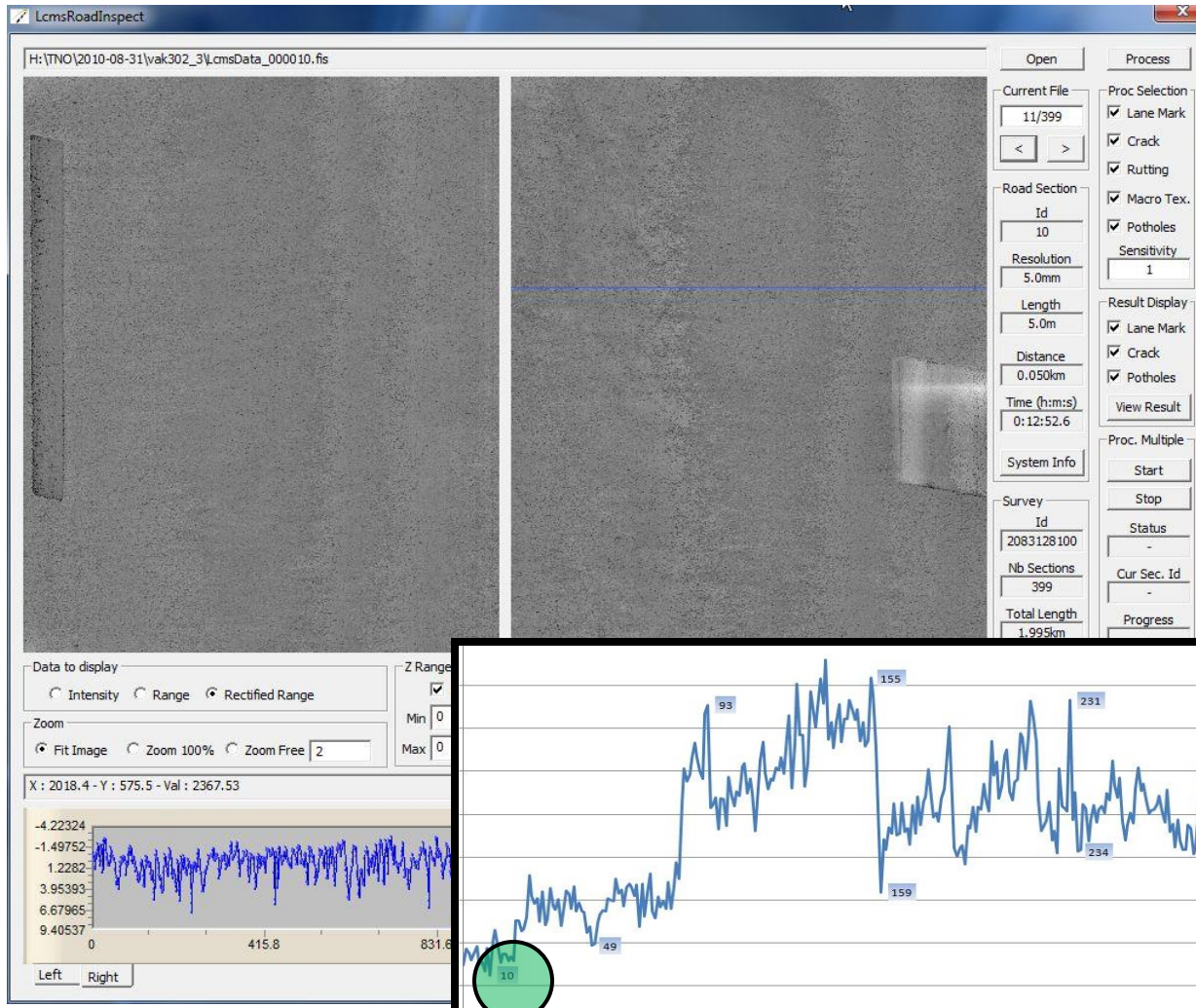




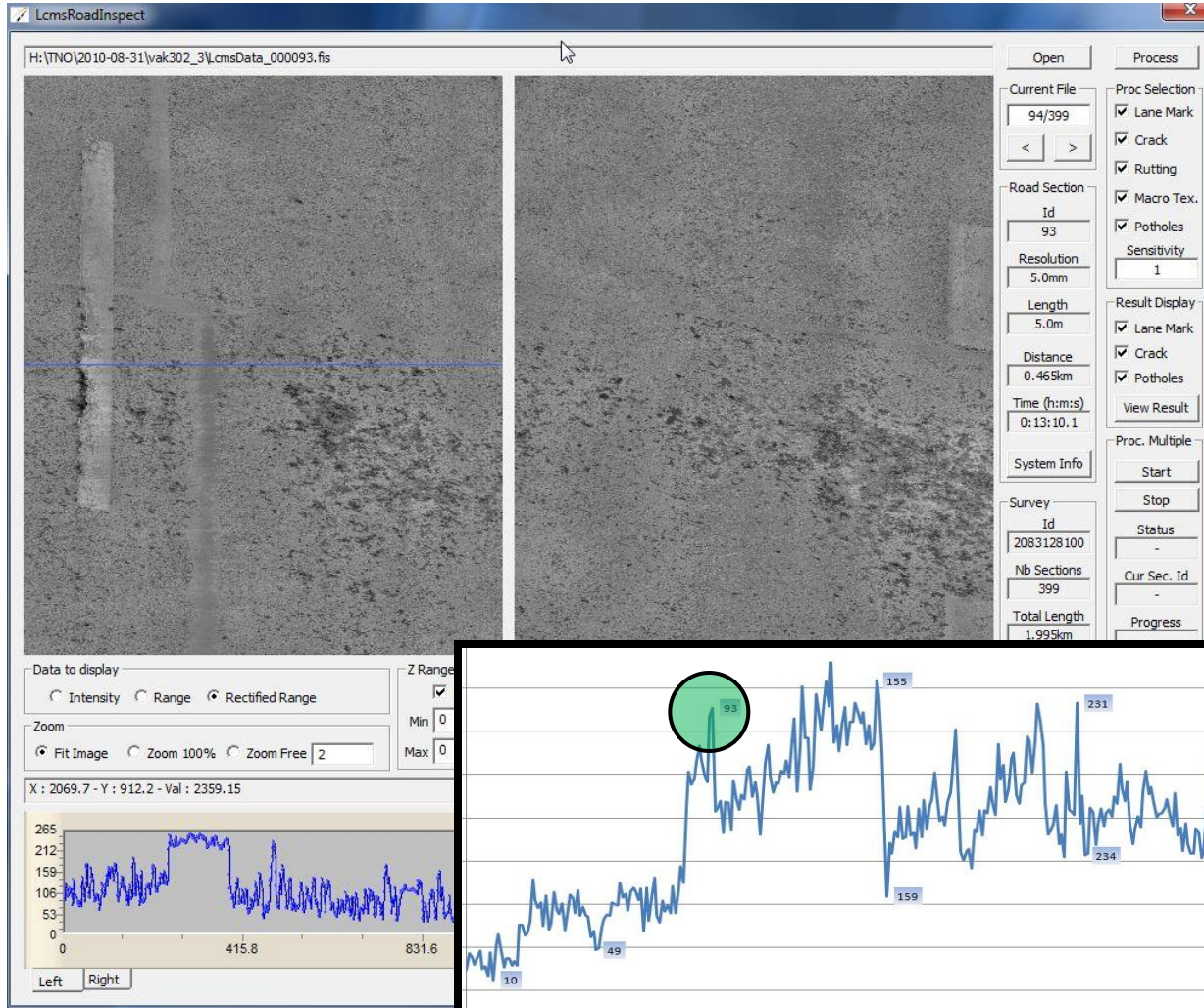
Aggregate loss detection



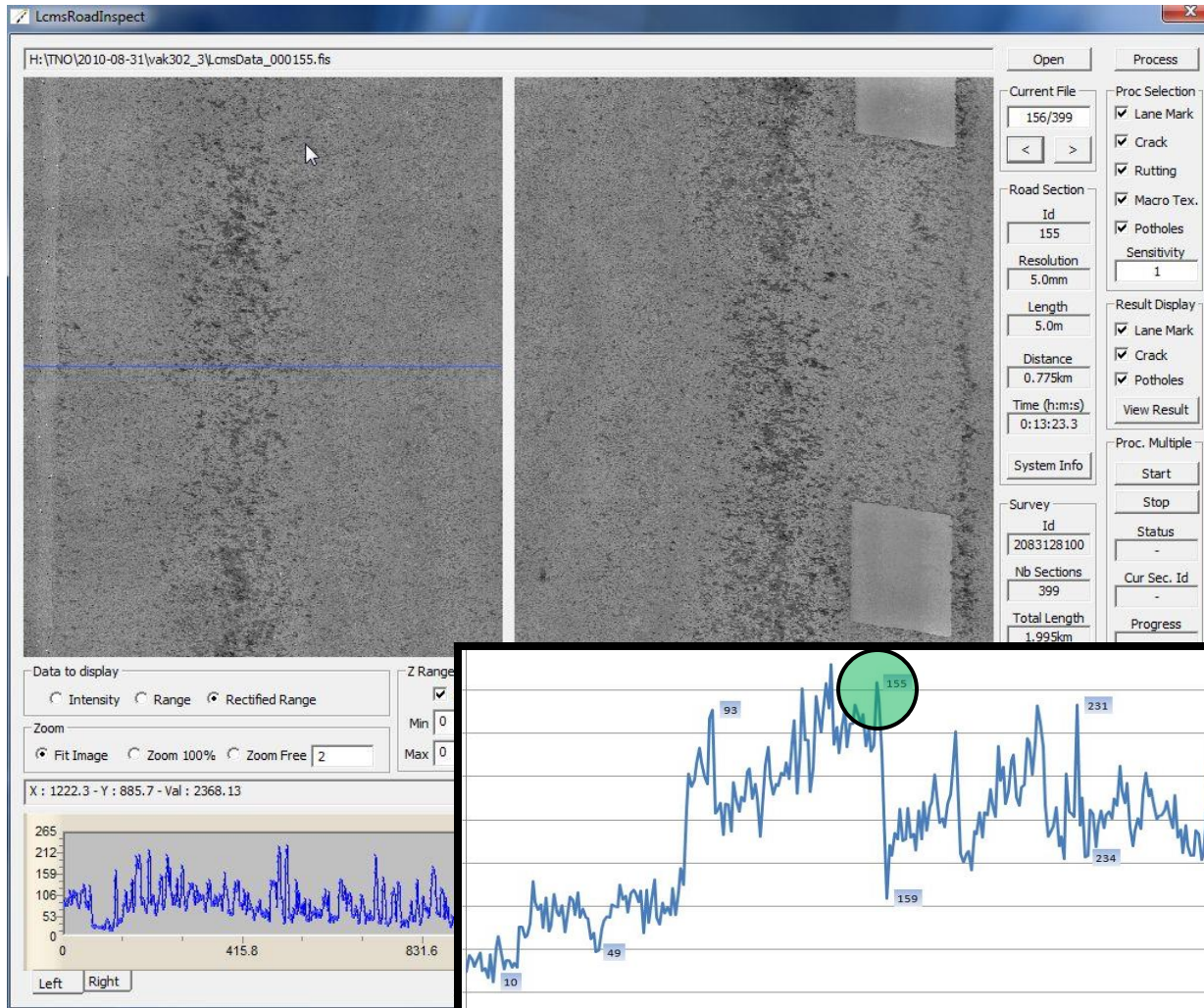
RI – Road test – Porous Asphalt in the Netherlands



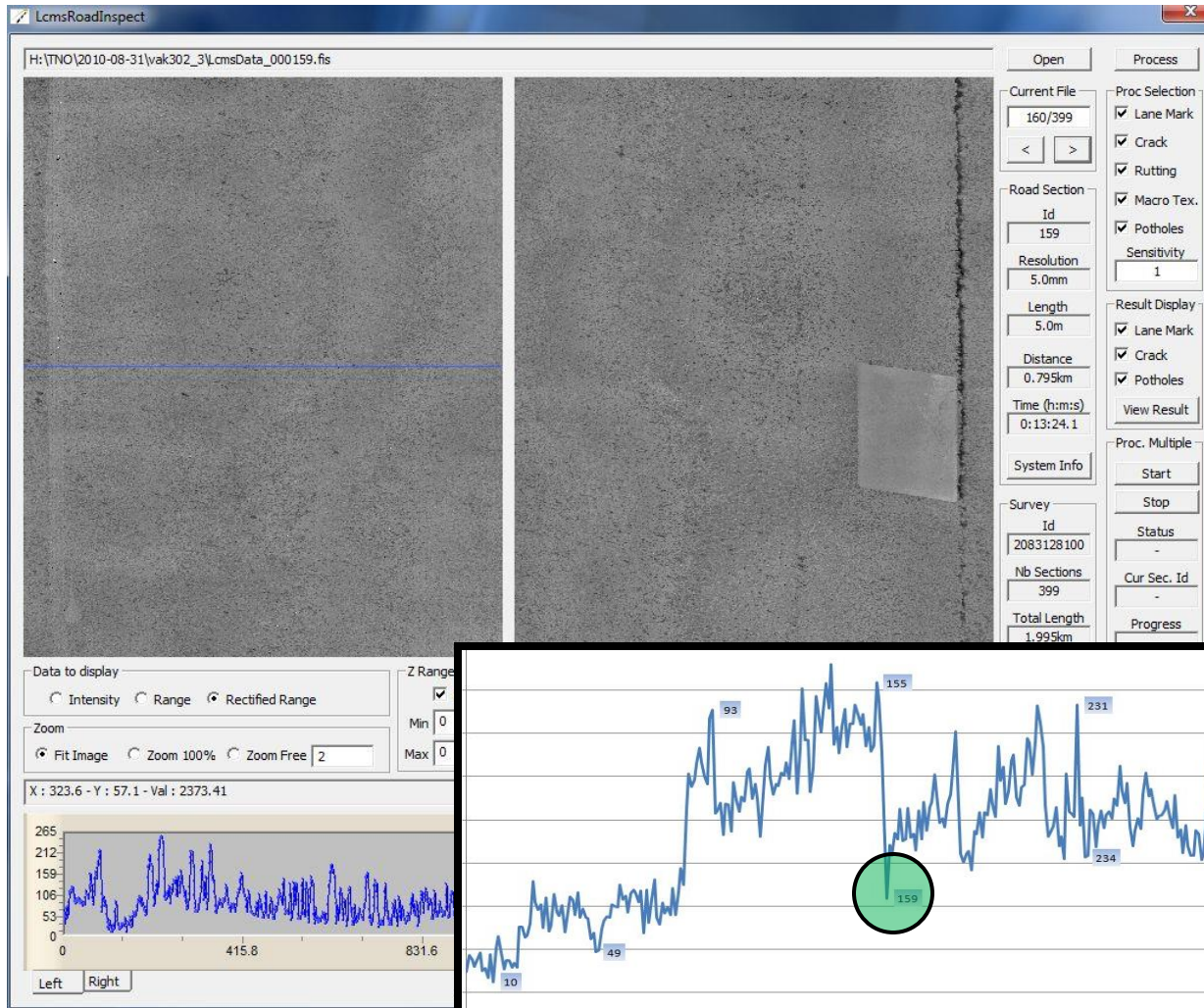
Road Section #93 : Transition between Ravelling and new pavement (Range)



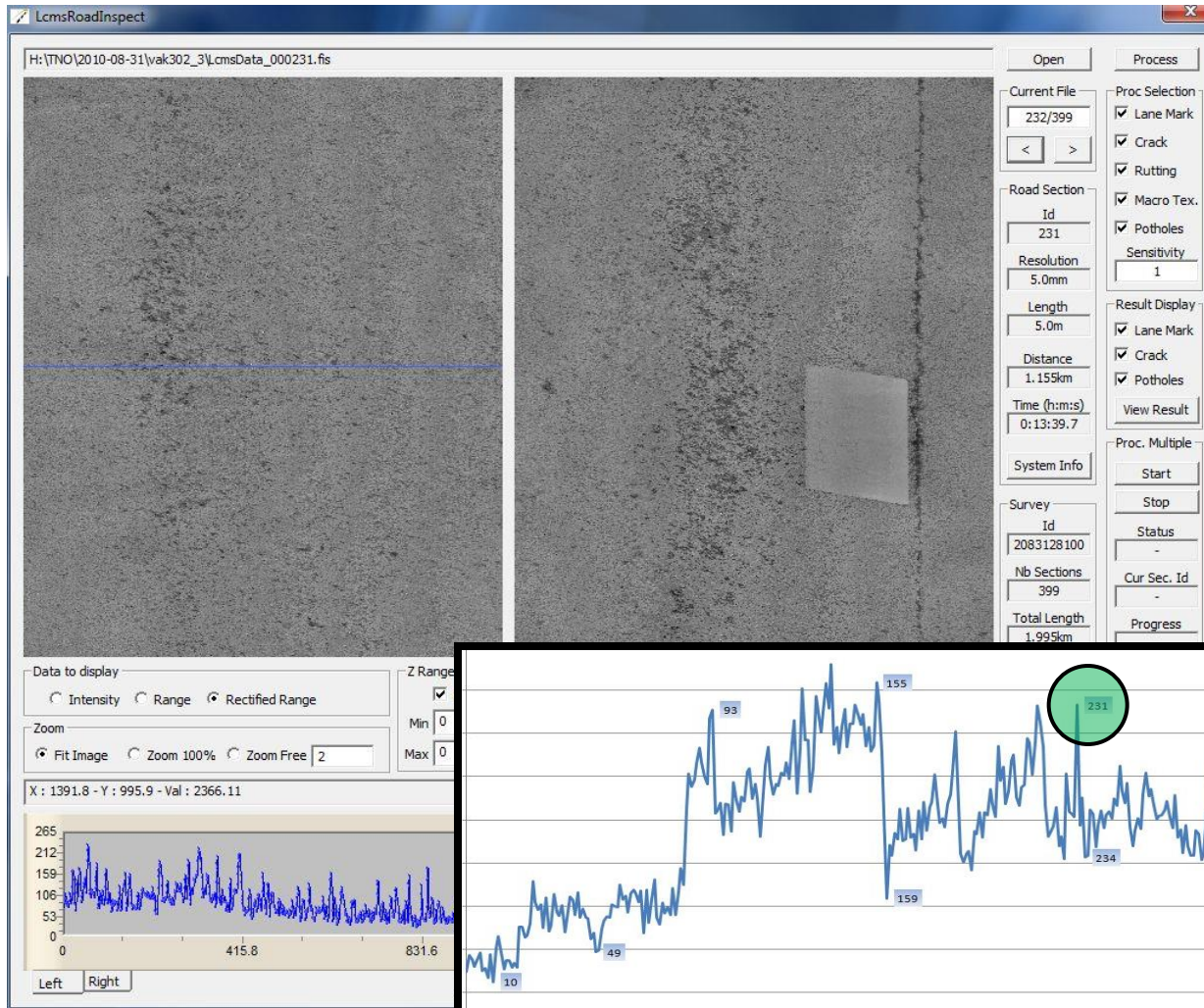
Road Section #155 : Raveling patch



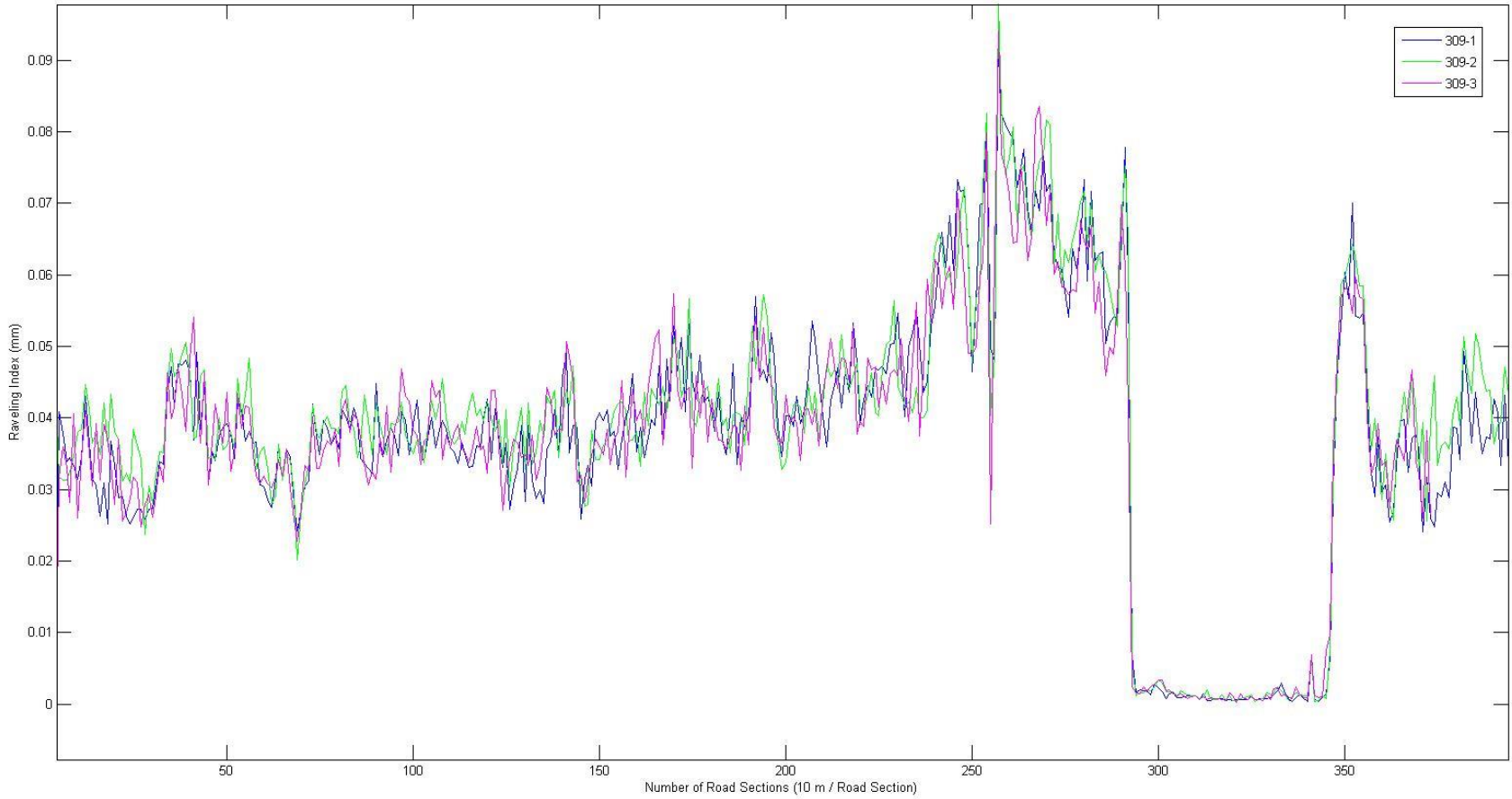
Road Section #159 : Smooth texture



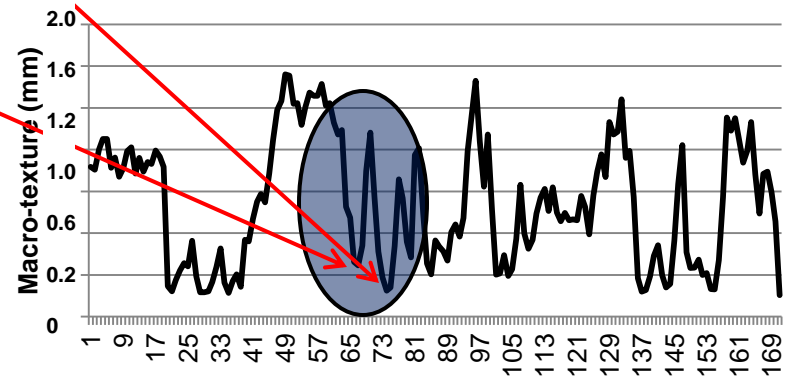
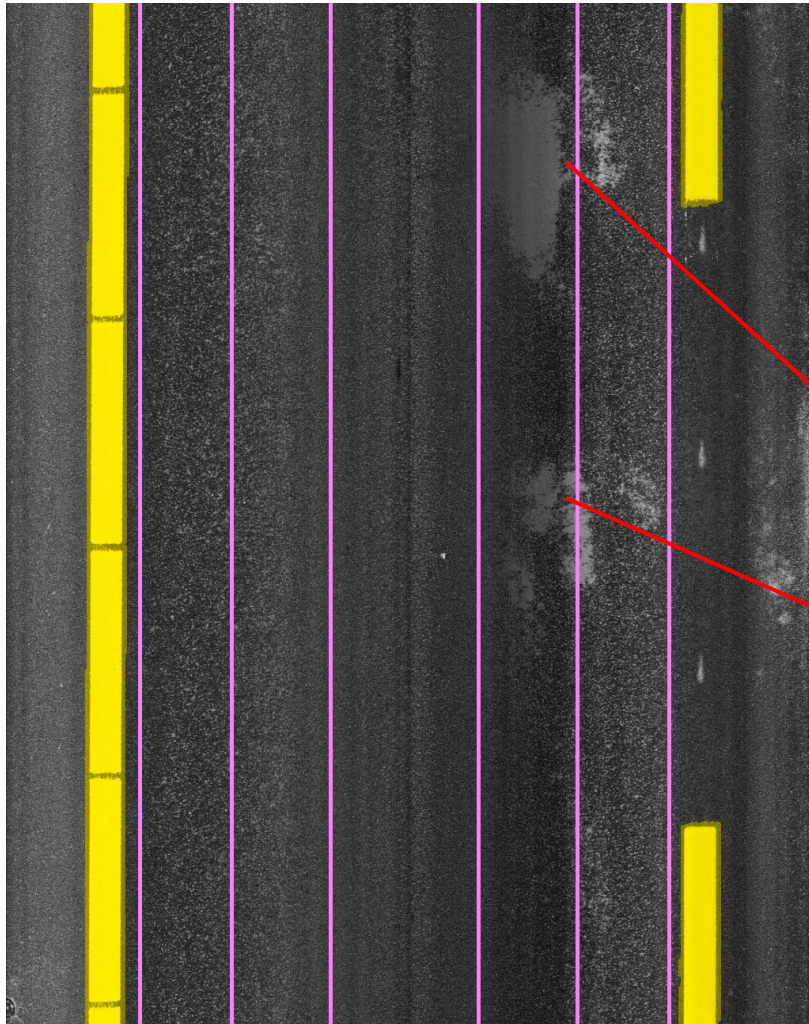
Road Section #231 : Raveling patch



Ravelling Index - Repeatability (Porous asphalt Netherlands)



Bleeding



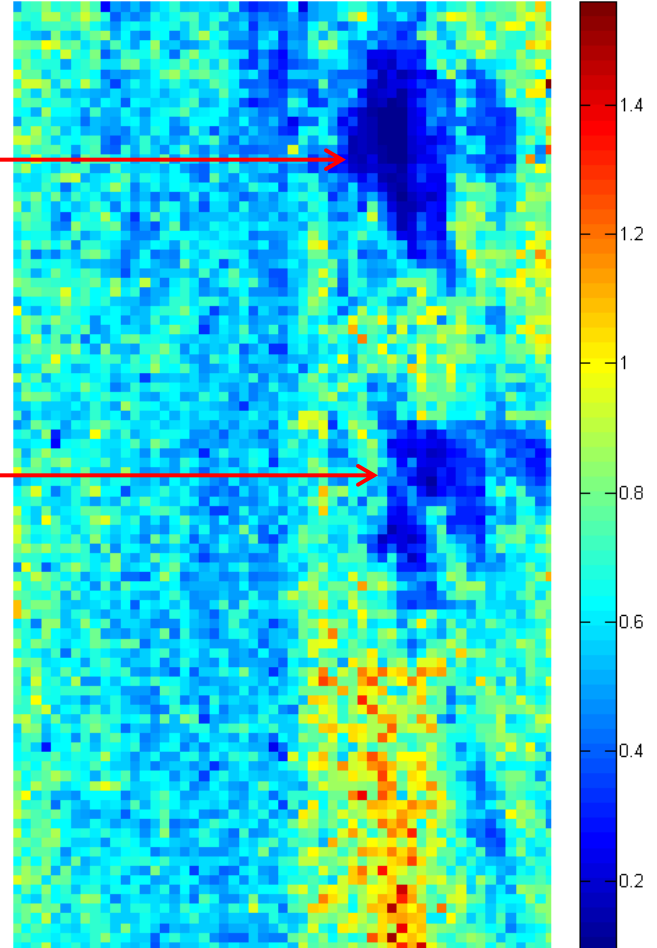
Index (each road section has 19 macro-texture values (1-19 = Section 1, 20-38=section 2, etc...))

Macrotexture: bleeding

Intensity image



Texture image (MTD, mm)



Pavemetrics

Concrete roads



Pavemetrics

Concrete Roads



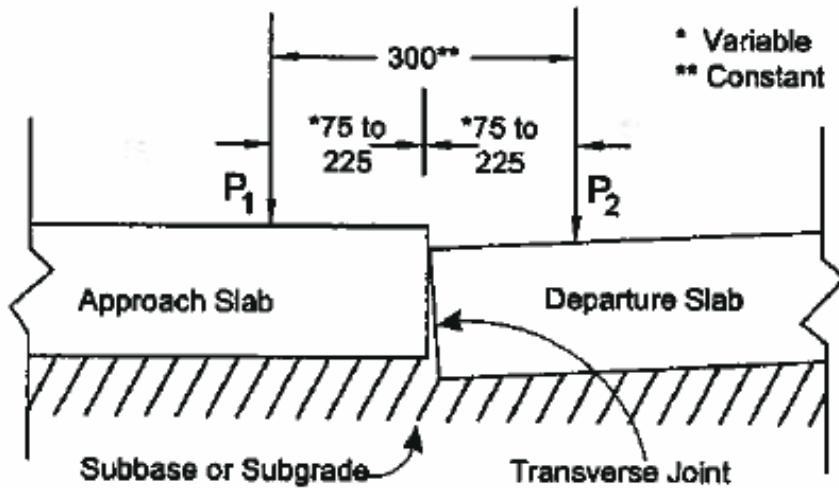
The logo for Pavemetrics, featuring a white circle with a black dashed line and a yellow arc above it.

Pavemetrics

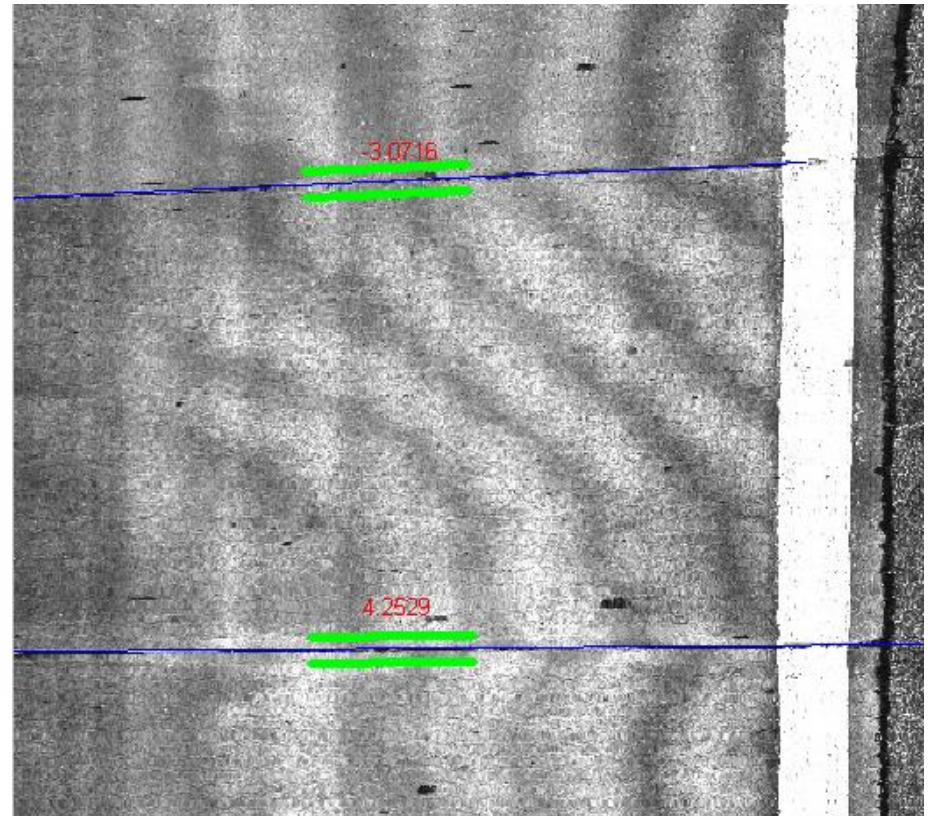
Concrete Roads



Joint detection and faulting

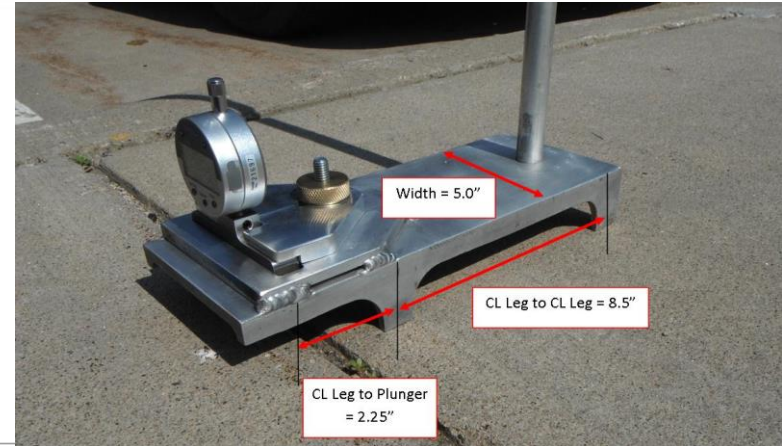


Note: All dimensions shown in millimeters unless otherwise noted.

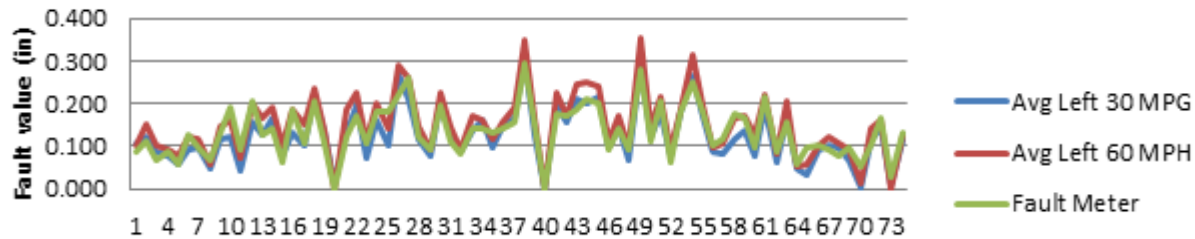


Faulting tests (South Dakota DOT)

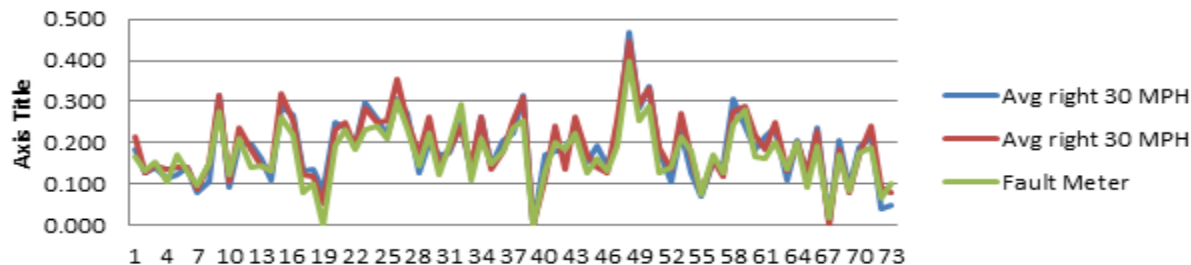
SD DOT faulting	30 and 60mph
Repeatability (LCMS)	0.98 (Correlation)
Average Bias (vs Faultmeter)	<0.5mm
LCMS vs Faultmeter	>0.92 (Correlation)



LCMS vs Fault Meter (Left wheel path)



LCMS vs Fault Meter (Right wheel path)



ASTM E950 Class 1 Device for Longitudinal Profiling



untitled] * - ProVAL 3.3

Close Add Files Save Report Viewer Editor Analysis PB Analysis

Project View Profile Selection Display Tools

Show Events Use Mileposts Units Help Options Screenshot

Precision and Bias

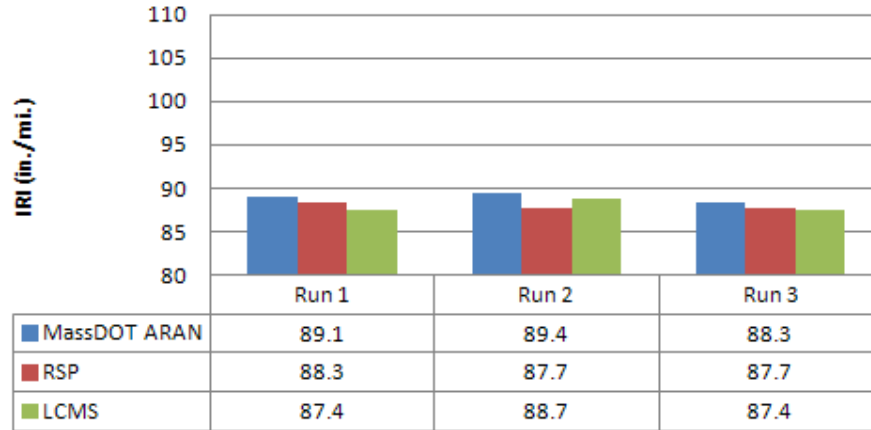
File	Profile	Basis	Section	Sample Interval (mm)
LcmsLongProfile_112737672_B9m_L380m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112737901_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112738110_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112738368_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112738611_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112738881_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112739136_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112739376_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112739684_B8m_L381m_s300mm_L	<input checked="" type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000
LcmsLongProfile_112739915_B8m_L381m_s300mm_L	<input type="checkbox"/> LElev	<input type="checkbox"/>	Full	300.000000

Result	Value
Bias (mm)	1.176
Precision (mm)	0.237
Bias Classification	1
Precision Classification	1

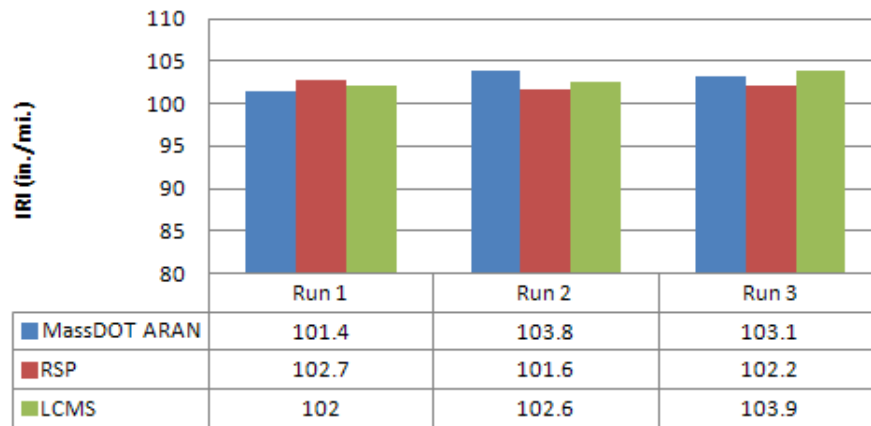
IRI \updownarrow

Distance \longrightarrow

MassDOT IRI Repeatability Runs (Left)



MassDOT IRI Repeatability Runs (Right)



Does it work?

LCMS vs Surpro

IRI values calculated for 4 LCMS runs on a 400m validation test track

Run	IRI Left (m/km)	IRI Right (m/km)
1	1.19	1.64
2	1.16	1.51
3	1.19	1.54
4	1.21	1.55
Mean	1.19	1.56
Standard deviation	0.02	0.06
Surpro	1.21	1.54

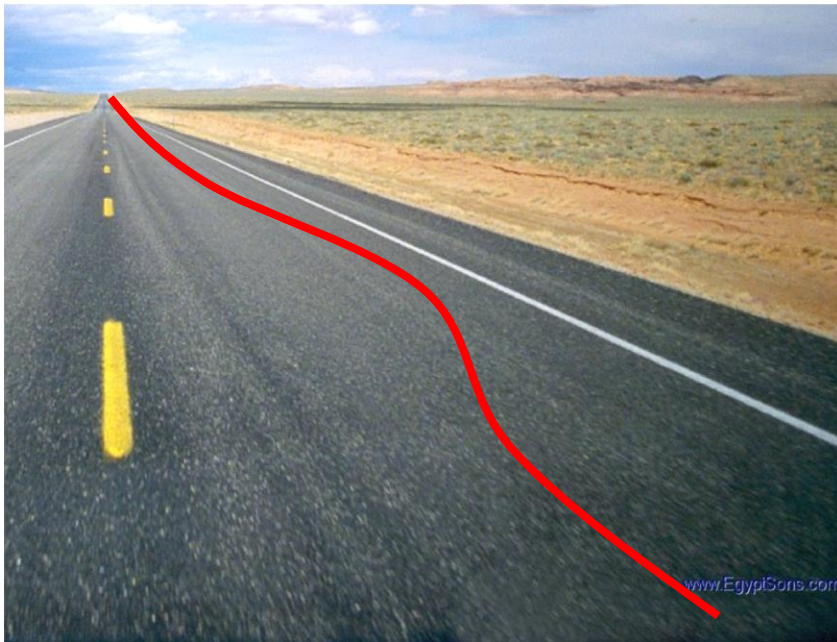
- IRI values are stable and close to the values obtained with the reference instrument (Surpro).

LCMS vs single point IRI

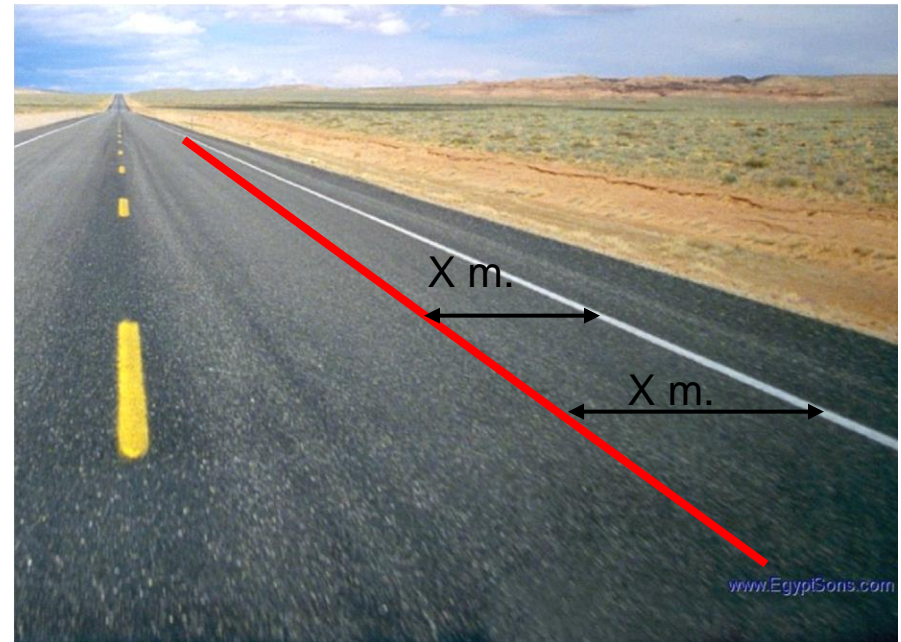


LCMS benefits

- LANE MARKINGS are used to correct profiles and compensate for driver wander.
- Simplifies certification procedures
- Eliminates the need to certify operators



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



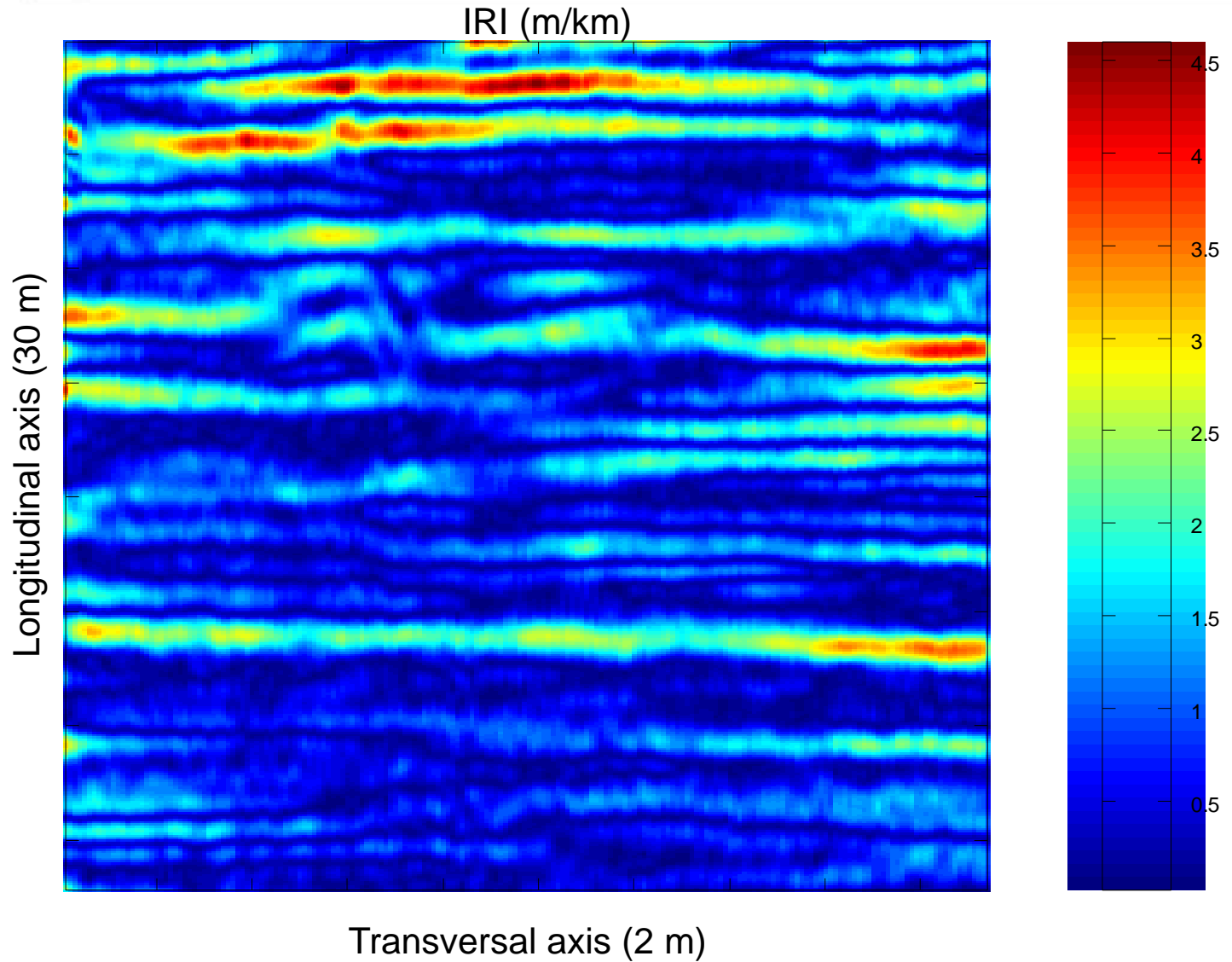
LCMS-IRI system: Erratic trajectory of the vehicle will still result in straight elevation profiles

Results: lane tracking

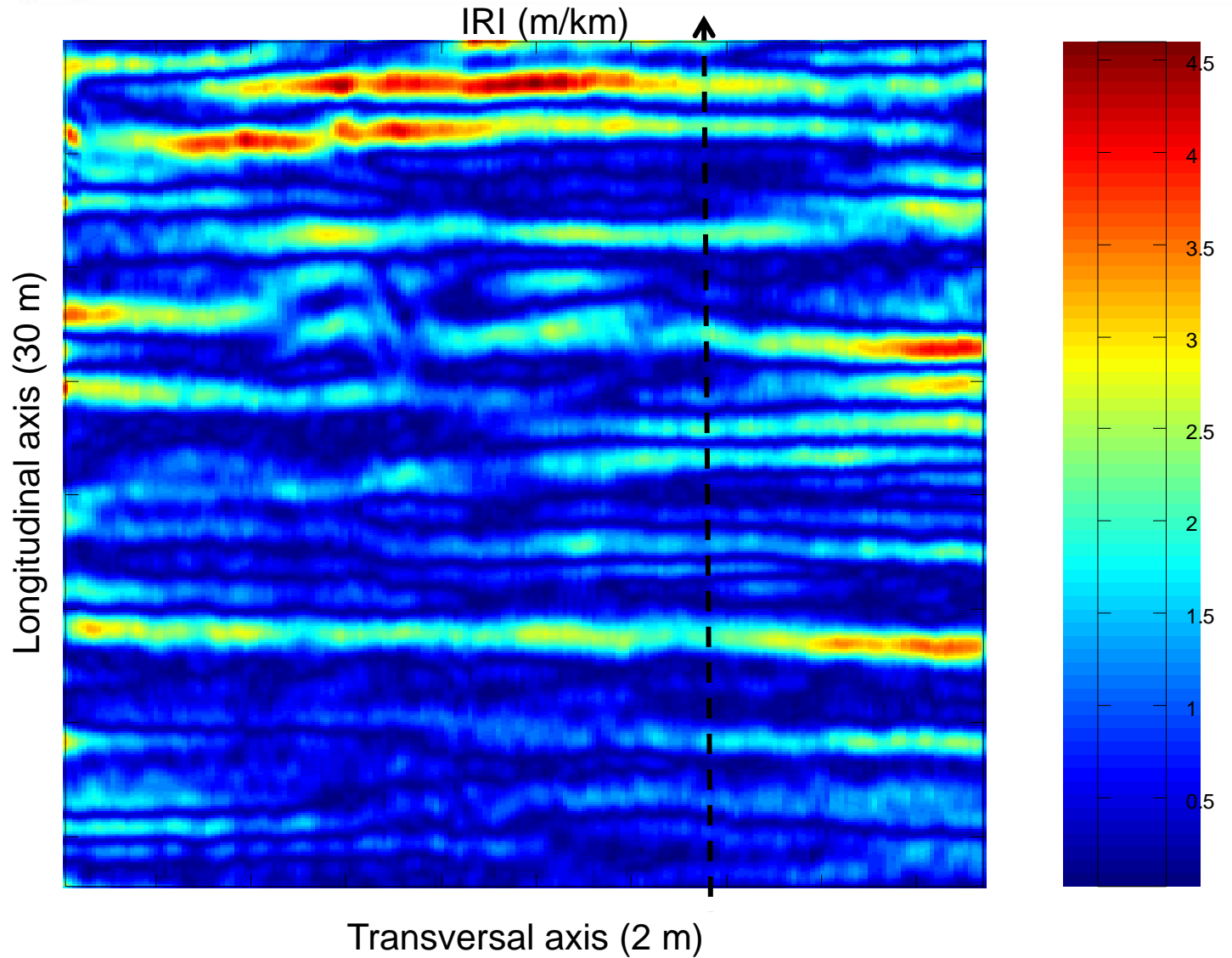
- Driver was asked to zigzag on validation track #1 (400 m).
- Elevation profiles computed with and without lane tracking.

	With lane tracking		No lane tracking	
Run	IRI Left (m/km)	IRI Right (m/km)	IRI Left (m/km)	IRI Right (m/km)
1	1.33	1.50	1.16	1.43
Reference value	1.29	1.47	1.29	1.47
Difference	3.1%	2.0%	10.1%	2.7%

Results: IRI image (2 x 30m)



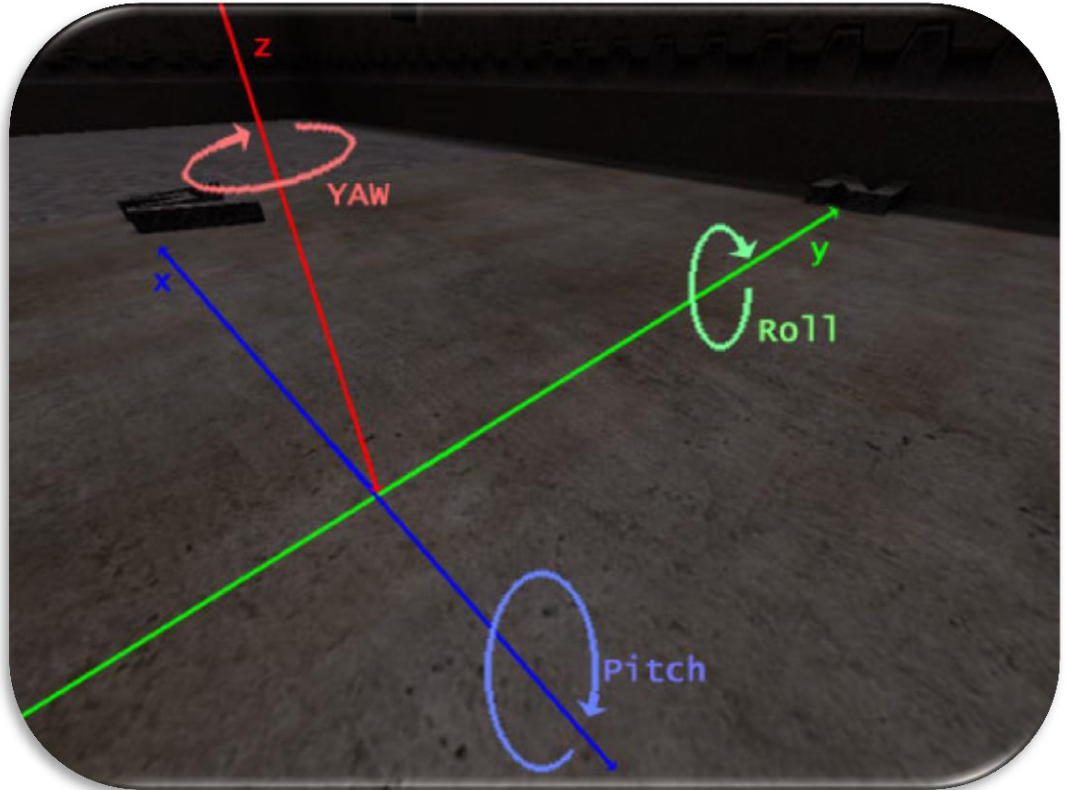
Results: IRI image (2 x 30m)



Pavemetrics

Road Geometry



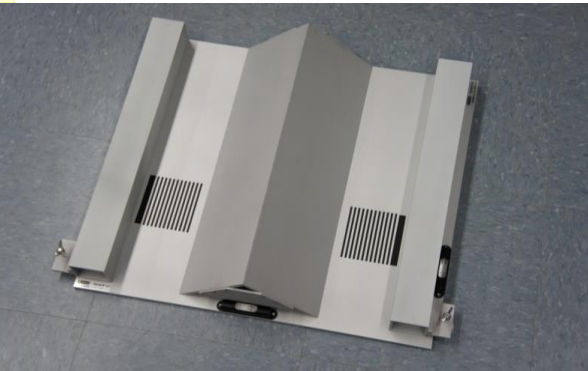


LCMS sensor/IMU coordinates transformation

IMU



Sensor to sensor and world (gravity) position calibration



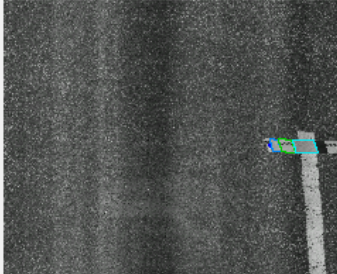
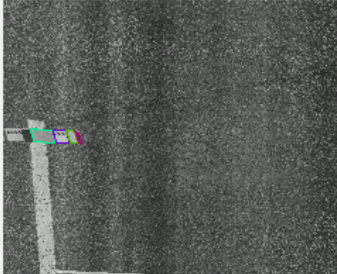
LcmsCalibrationTool

Step 1 | Step 2 | Step 3 | Step 4

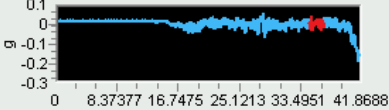
Step 2 - 3D And Vehicle Level Calibration

Open Survey: D:\Temp\LcmsData\2013_07_31\Acqui0001\LcmsData_000004.fis


Process: Processing done

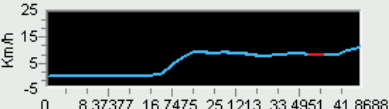
Imu Acceleration - Lateral




Imu Acceleration - Forward



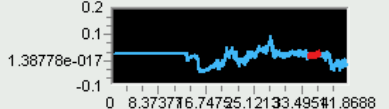
Vehicle Speed



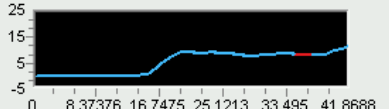
Imu Acceleration - Lateral



Imu Acceleration - Forward



Vehicle Speed



Target Detection

First Profile: 884 Last Profile: 1056

3D Calibration Results

	Tx	Ty	Tz	Unit
Translation L-R	-1614.8	34.86	6.14	mm
Sensor Angle L-R	L: 16.47	R: 14.51		deg
Target Position	-774.42	4622.34	2225.05	mm
Target Rotation	Rx: 0.29	Ry: -179.26	Rz: 2.80	deg
Lcms Orientation	Rx: -0.25	Ry: 0.75	Rz: 0.00	deg
RMS Reprojection Error	0.76			mm

Imu Orientation - Levelled

	Rx	Ry	Rz	Unit
Left	1.43	0.14	163.32	deg
Right	1.06	-0.47	163.89	deg

Calib Stop and Go : Success!

Calib Stop and Go - INS - : Success!

Step2: Loaded survey with 6 valid RoadSections

Calib 3D Target Detection : Success!

Calib Vehicle level : Success!

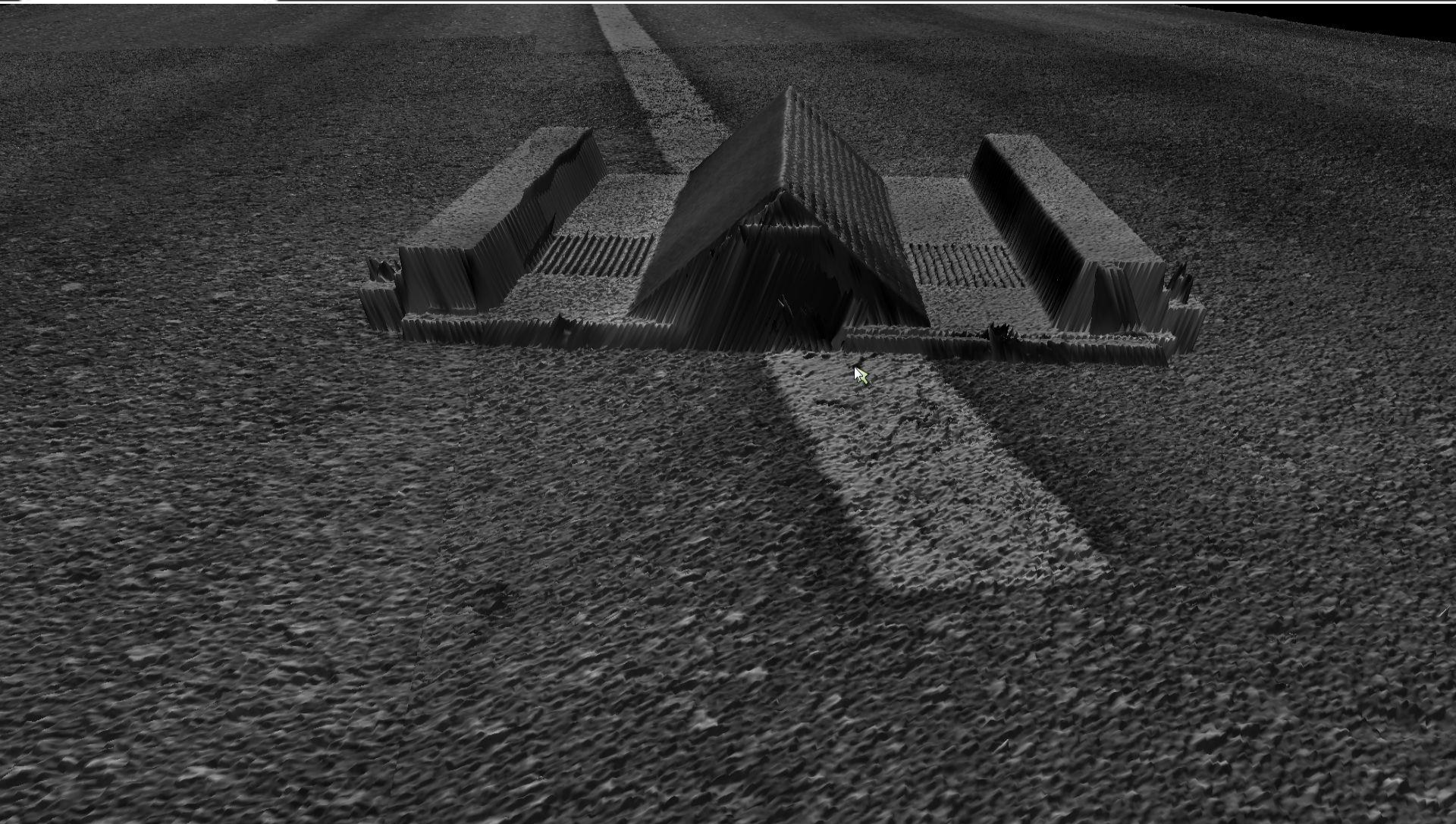
Calib Vehicle level Ins Platform: Success!

Calib 3D : Success!

Sensor to sensor and world (gravity) position calibration



Sensor to sensor and world (gravity) position calibration



Wheel/encoder vs IMU coordinates transformation

LcmsCalibrationTool

Step 1 | Step 2 | Step 3 | Step 4

Step 3 - Vehicle Configuration

Right Side

2 - 2306 mm

Rear

1 - 250 mm

3 - 2415 mm

DMI location Left Right

Step 3 Procedure

Enter the 3 following measurements and select the DMI side:

- 1 - Lateral distance between the RIGHT sensor and the center of the RIGHT wheel (positive distance : the sensor is on the left of the RIGHT wheel)
- 2 - Distance between the RIGHT sensor and the rear axel
- 3 - Center to center distance between the rear wheels

Validation information

Lateral offset between the center of the LCMS system and the center of the vehicle, as seen when looking at the rear of the vehicle. This offset is computed from the calibration results and the provided measurements about the vehicle configuration. It can be used to validate the whole calibration procedure .The center of the LCMS system is defined as the mid-point between the two sensors.

The LCMS system is offset by 150mm to right

INS platform position

Enter the position of the INS platform:
 * XY position must be given with respect to the center of the rear axel
 * Z is the height of the INS with respect to the laser output window of the Right sensor

X mm Lateral pos, positive if INS is located on the left side

Y mm Longitudinal pos, positive if INS is located in front of the rear axel

Z mm Height pos, positive if INS is located below the laser output window

Calib Stop and Go : Success!
 Calib Stop and Go - INS - : Success!
 Step2: Loaded survey with 6 valid RoadSections
 Calib 3D Target Detection : Success!
 Calib Vehicle level : Success!
 Calib Vehicle level Ins Platform: Success!
 Calib 3D : Success!

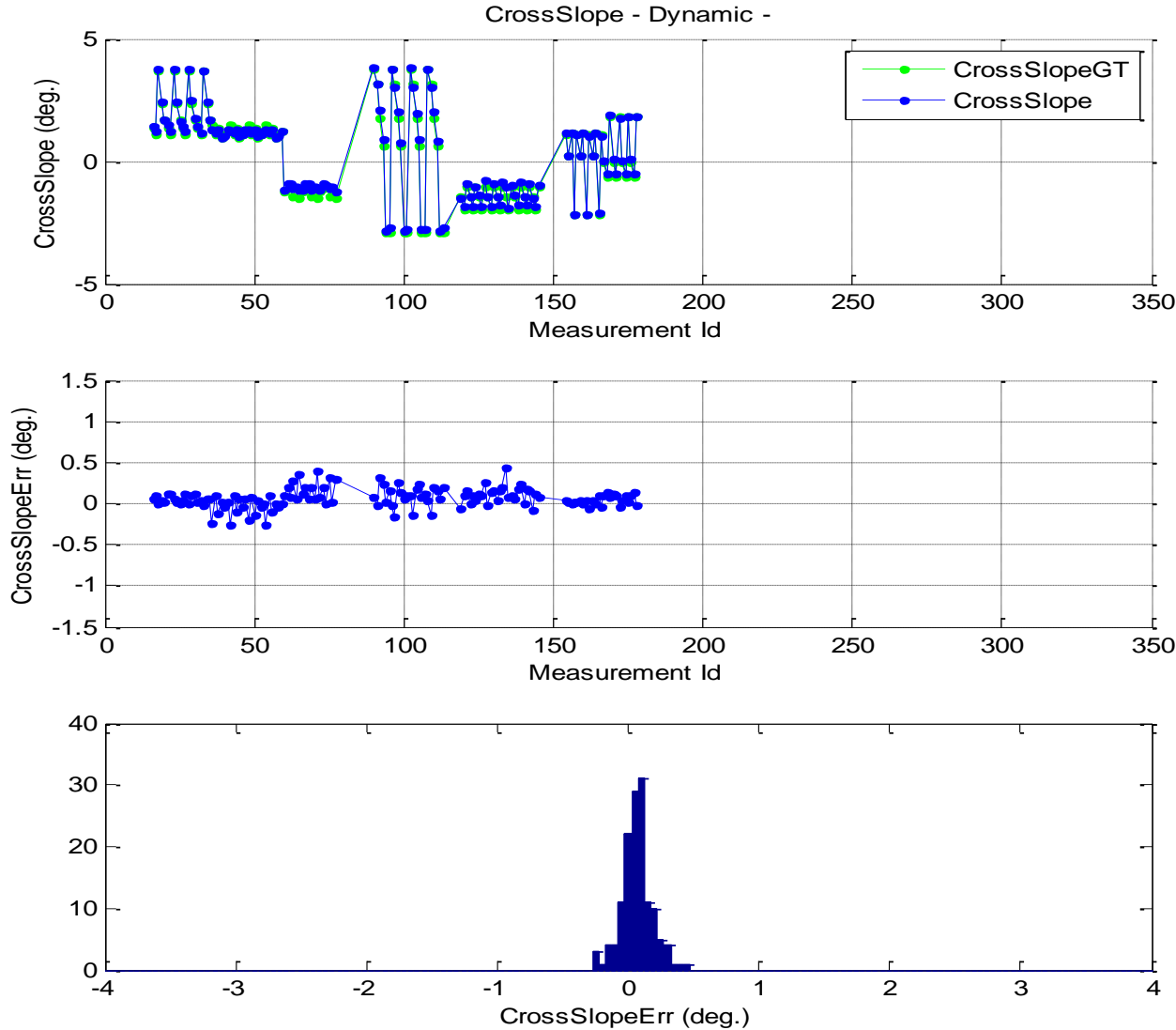


Field Validation Tests – Slope and Crossfall

Cross-slope: Dynamic vs GT

Mean XSlopeErr = 0.07deg
 Mean XSlopeErr = 0.13 %

Std Dev. XSlopeErr = 0.1 deg
 Std Dev. XSlopeErr = 0.2%



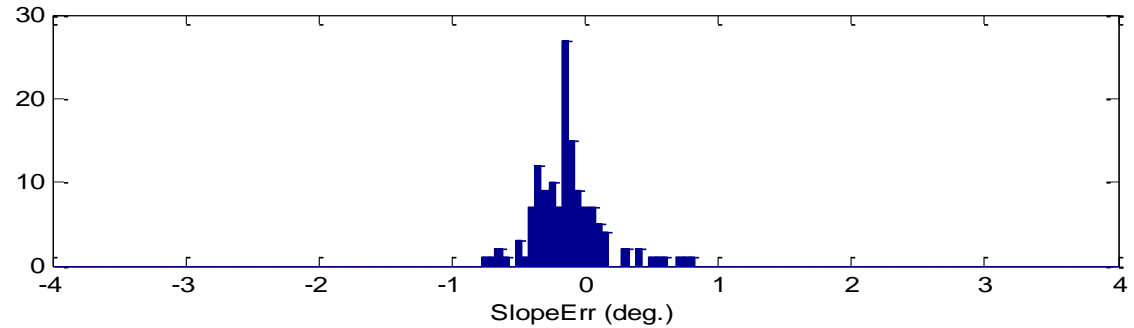
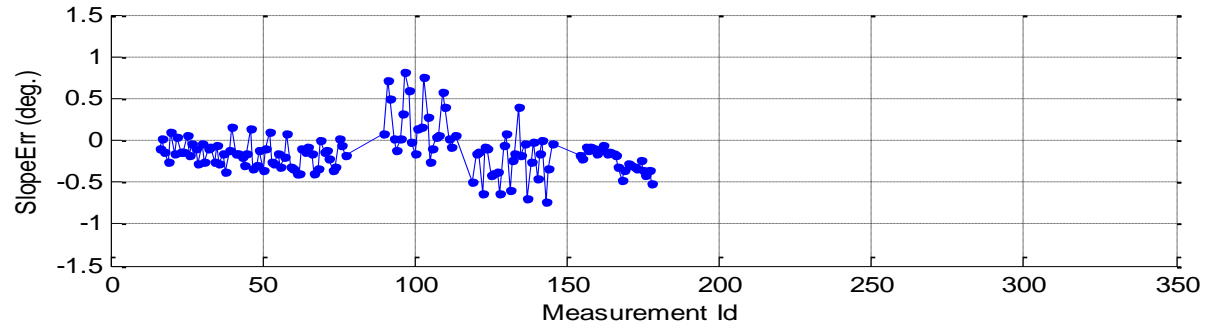
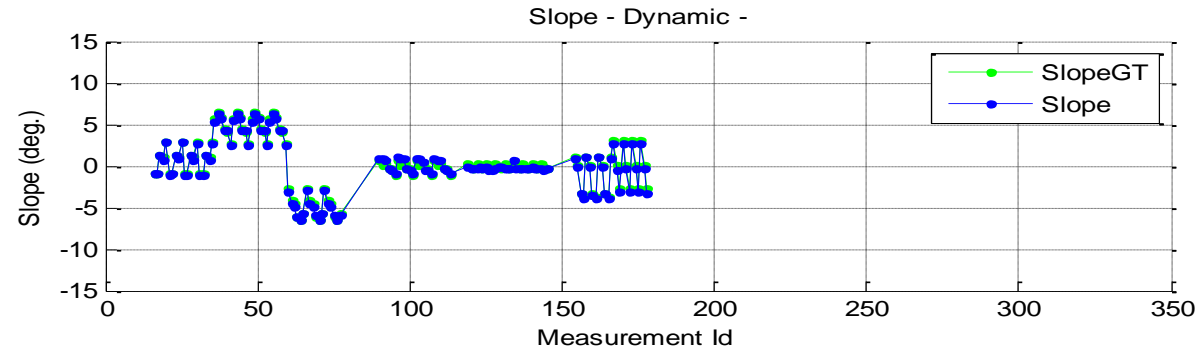
Slope: Dynamic vs GT

Mean SlopeErr = 0.13deg.

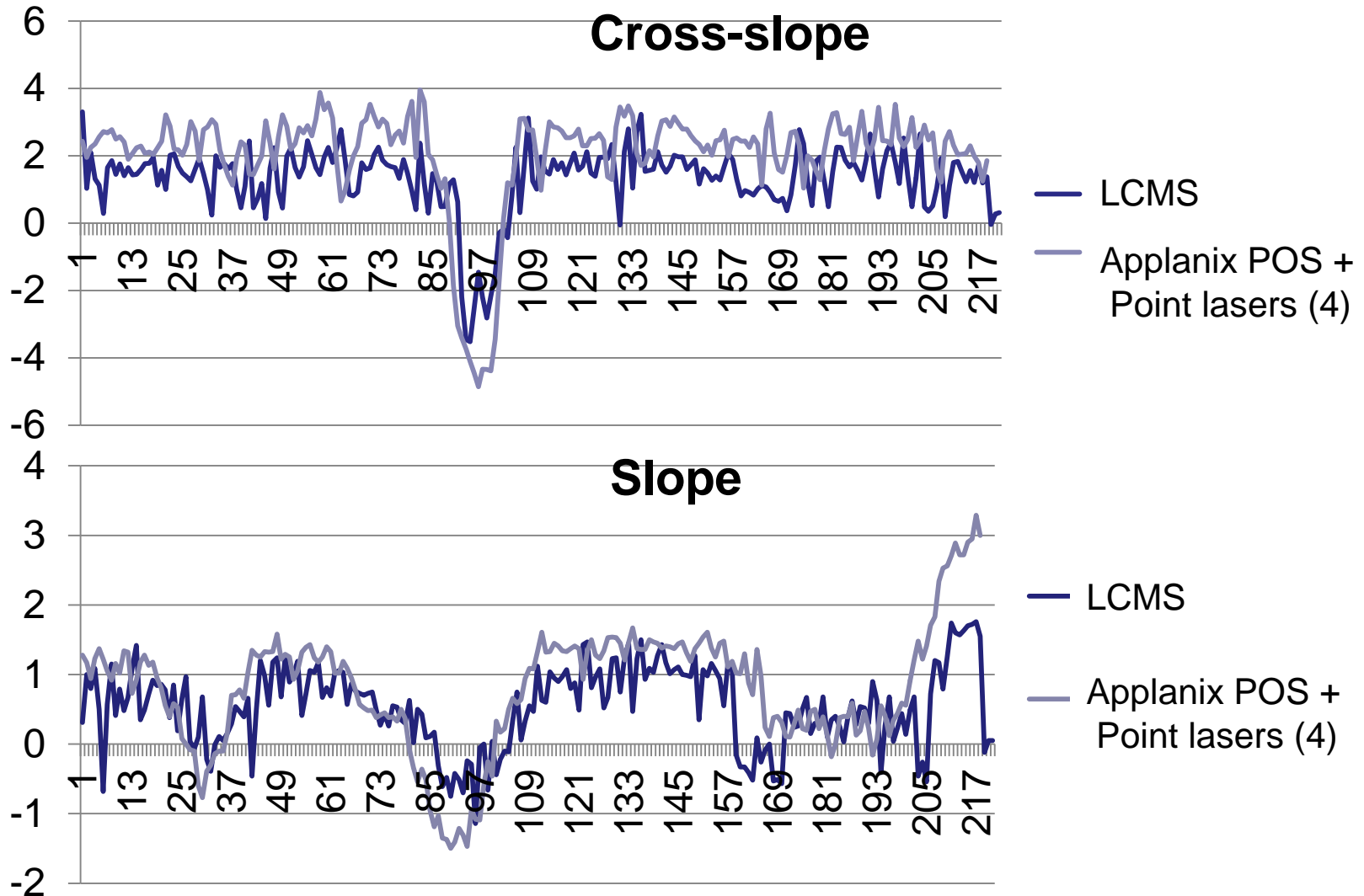
Mean SlopeErr = 0.25%

Std Dev. SlopeErr = 0.26deg.

Std Dev. SlopeErr = 0.46%



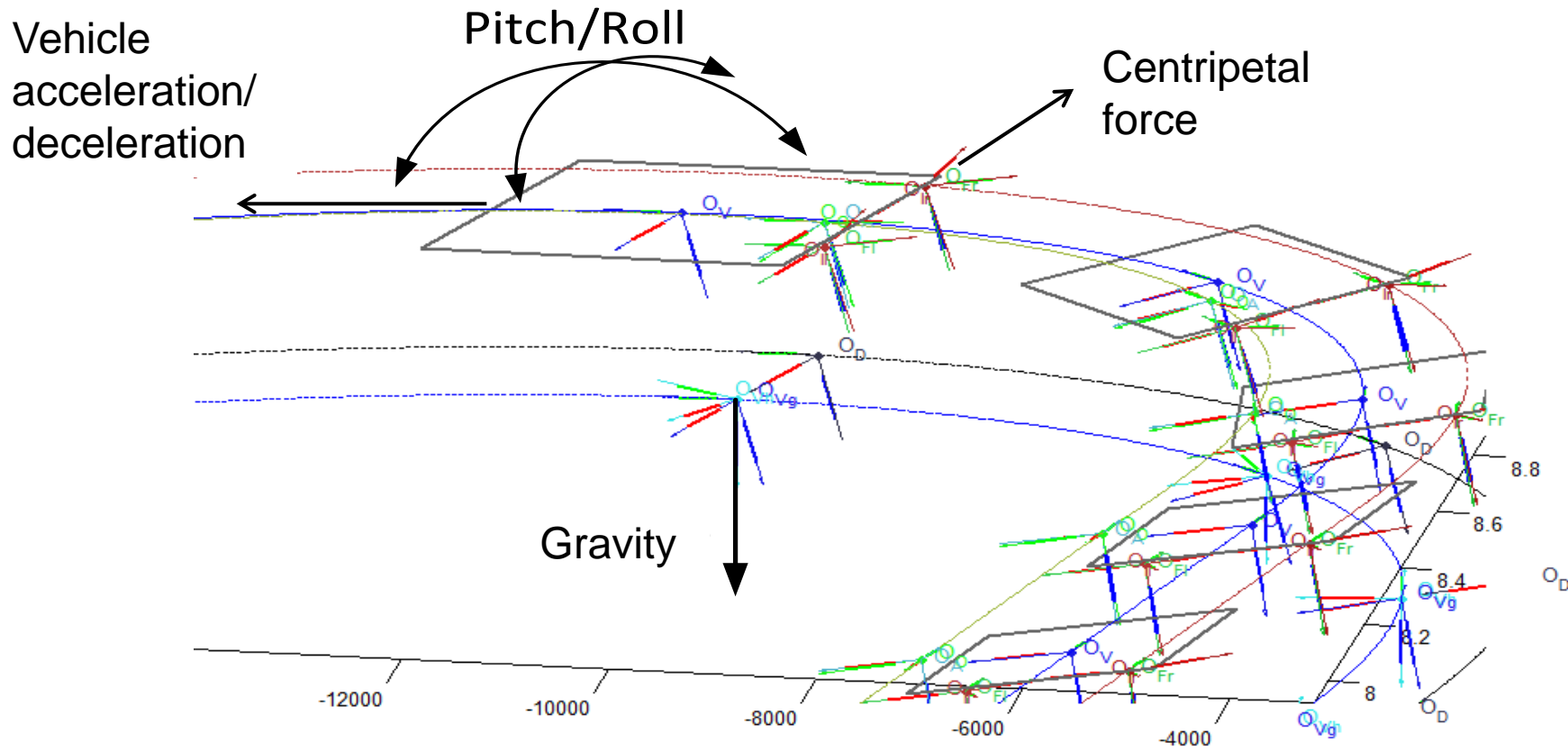
Road tests - Geometry



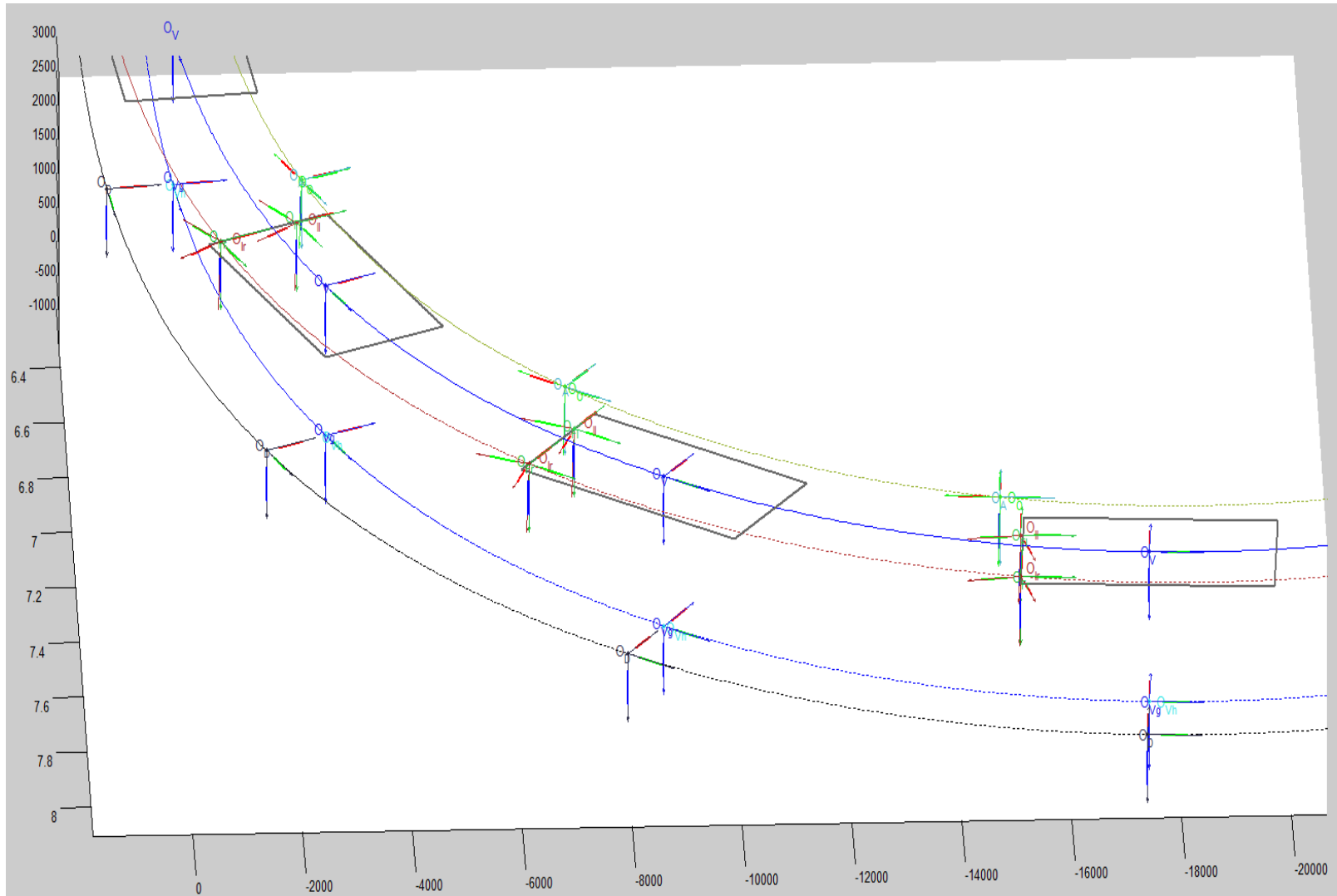


Terrain Mapping

Complex Vehicle Dynamics



Final result – Vehicle track and DTM

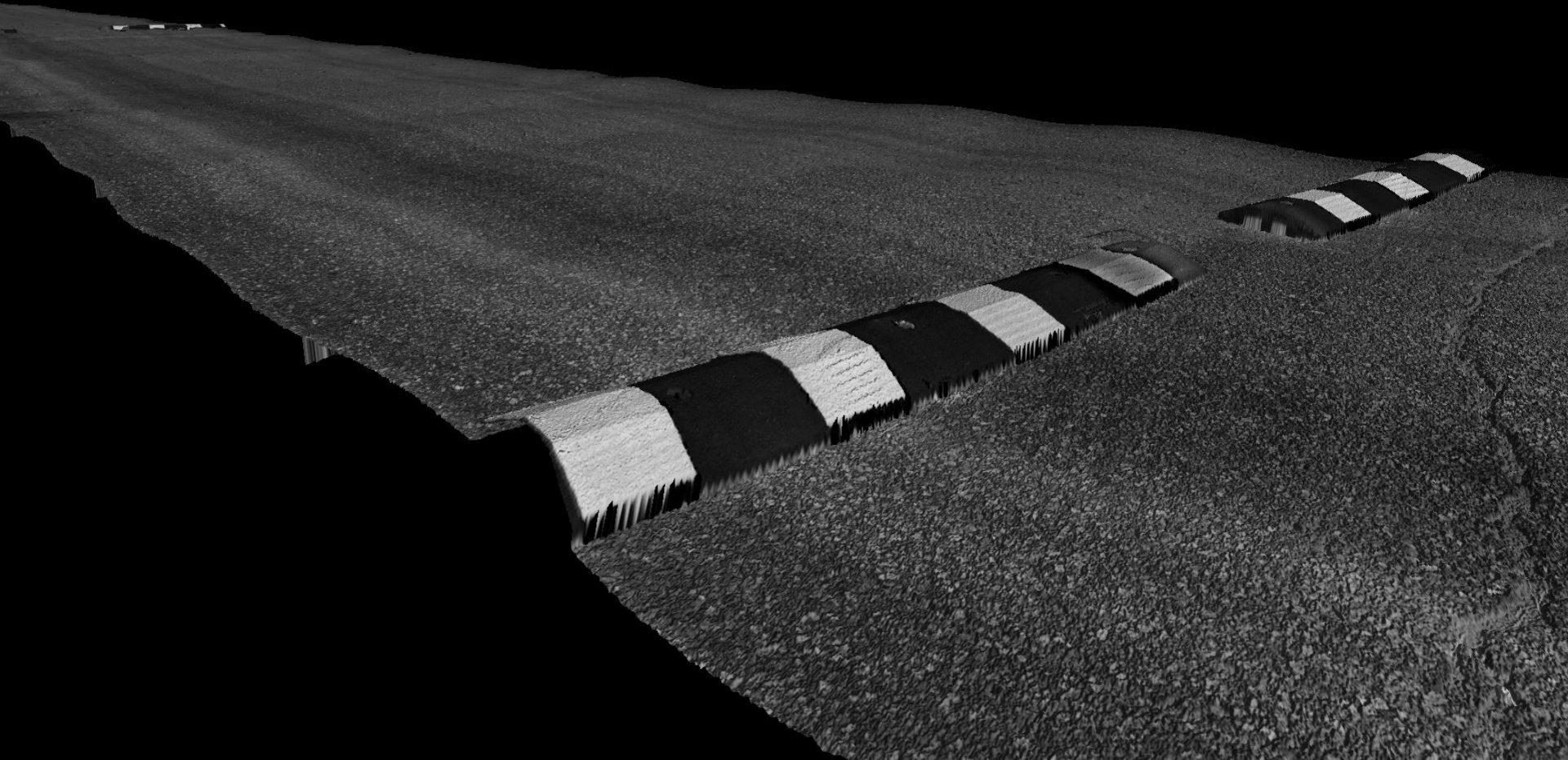


Pavemetrics

3D Road Profile Before Dynamic Corrections

D:\Temp\LcmsData\2013_07_31\Acqui\0009\LcmsData_000000.fis - LcmsPV3D

File View Help



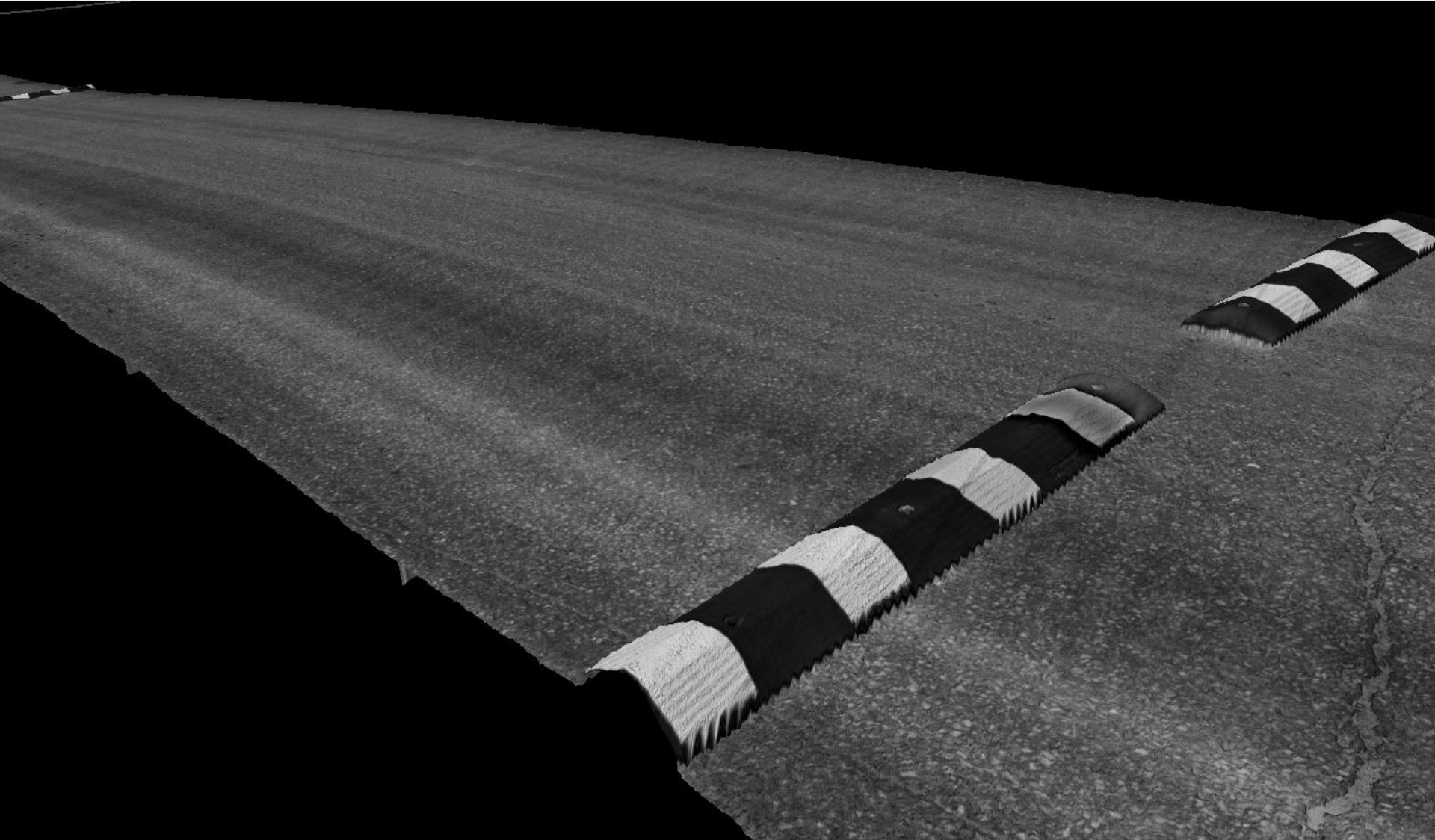
The logo for Pavemetrics, featuring the word "Pavemetrics" in a bold, sans-serif font. Above the text is a stylized graphic of a road with a dashed white line curving to the right, all enclosed within a white circular shape with a black border.

Pavemetrics

3D Road Profile After Dynamic Corrections

msData\2013_07_31\Acqui0009\LcmsData_000000.fis - LcmsPV3D

Help

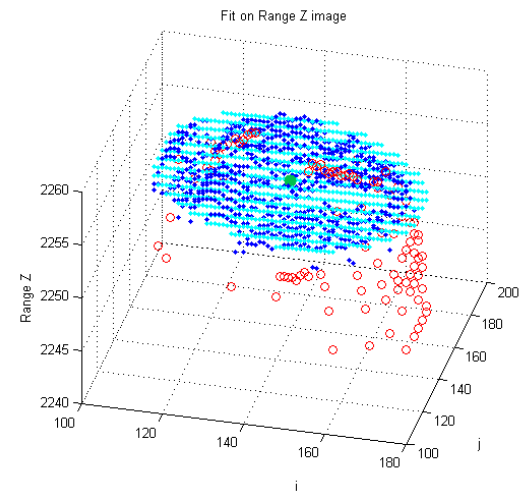
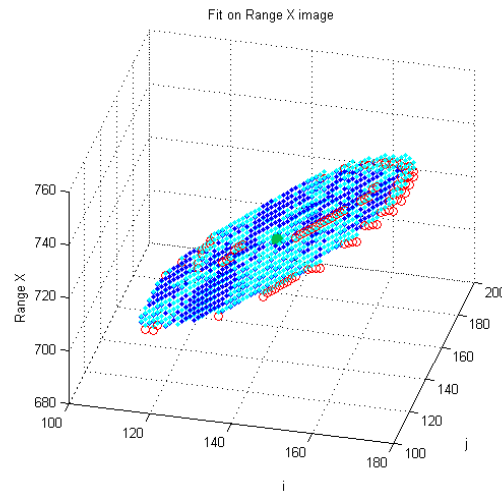
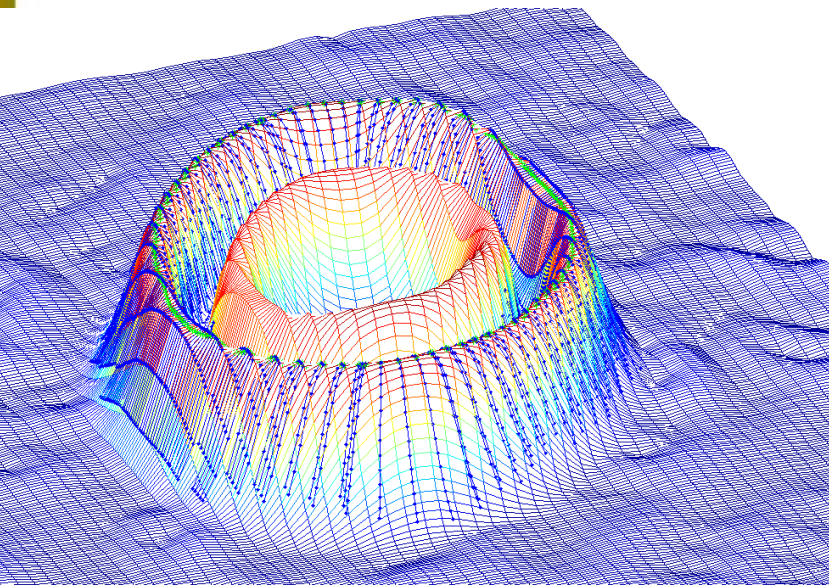
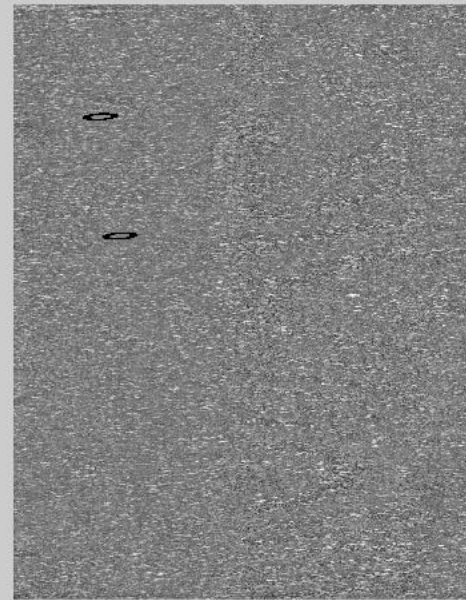
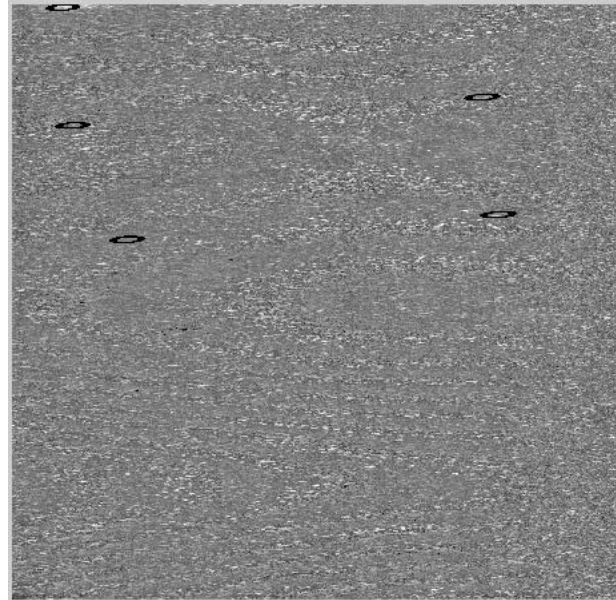
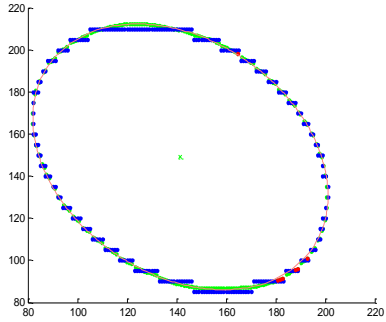


Pavemetrics

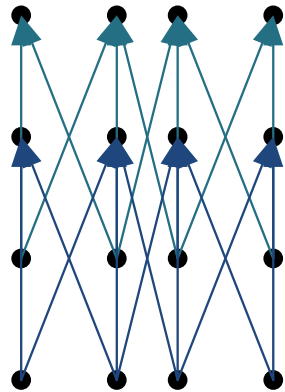
Field validation



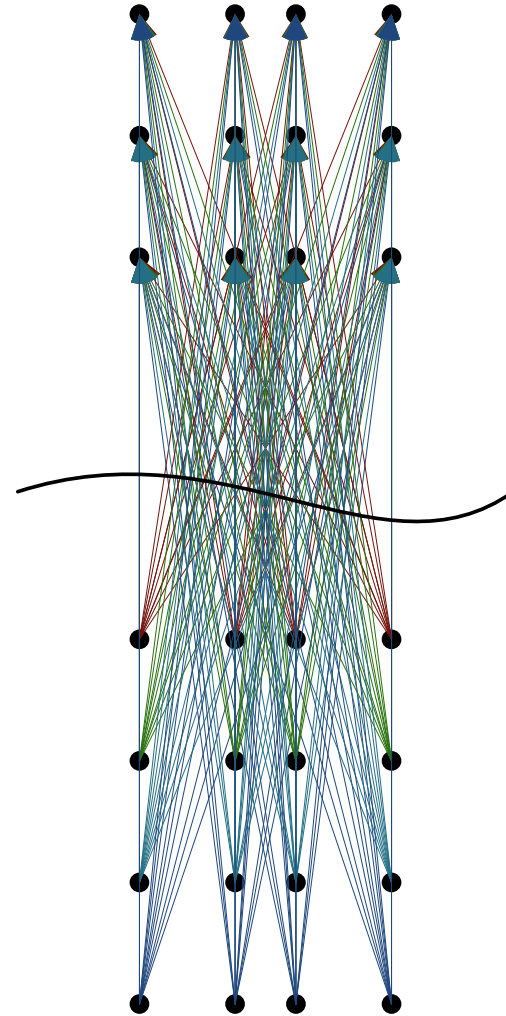
Field validation – Puck center evaluation



Field validation



Pairing pattern for the 4m test



Pairing pattern for the 67m test

Accuracy tests - RMS error

100% Inertial - 4m

Scan	RMS Registrati	RMS Geometry preservation error (mm)			
		X	Y	Z	Module
2	3.32	2.28	3.06	4.51	5.91
3	3.53	2.42	2.88	5.30	6.50
4	3.89	3.01	5.34	2.79	6.74
5	4.65	3.63	5.09	5.40	8.26
6	2.92	1.59	4.02	3.07	5.30
Mean	3.66	2.59	4.08	4.21	6.54

100% Inertial - 4m 2 known points

Scan	RMS Registrati	RMS Geometry preservation error (mm)			
		X	Y	Z	Module
2	3.11	2.30	2.09	4.50	5.47
3	3.33	2.42	2.07	5.27	6.16
4	3.34	3.02	3.89	2.78	5.65
5	4.26	3.63	3.77	5.38	7.51
6	2.45	1.59	2.75	3.02	4.38
Mean	3.30	2.59	2.91	4.19	5.83

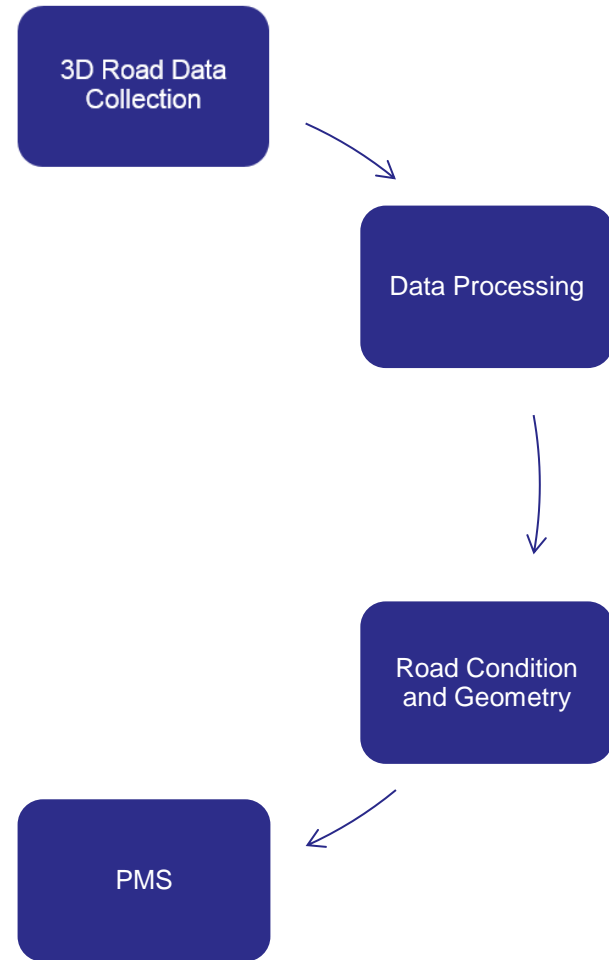
100% Inertial - 84m

Scan	RMS Registrati	RMS Geometry preservation error (mm)			
		X	Y	Z	Module
2	9.89	2.08	21.76	2.42	21.99
3	8.65	2.08	16.15	5.36	17.14
4	15.87	5.18	31.59	4.15	32.28
5	13.56	3.37	27.28	3.64	27.73
6	12.38	2.00	25.52	2.68	25.73
Mean	12.07	2.94	24.46	3.65	24.98

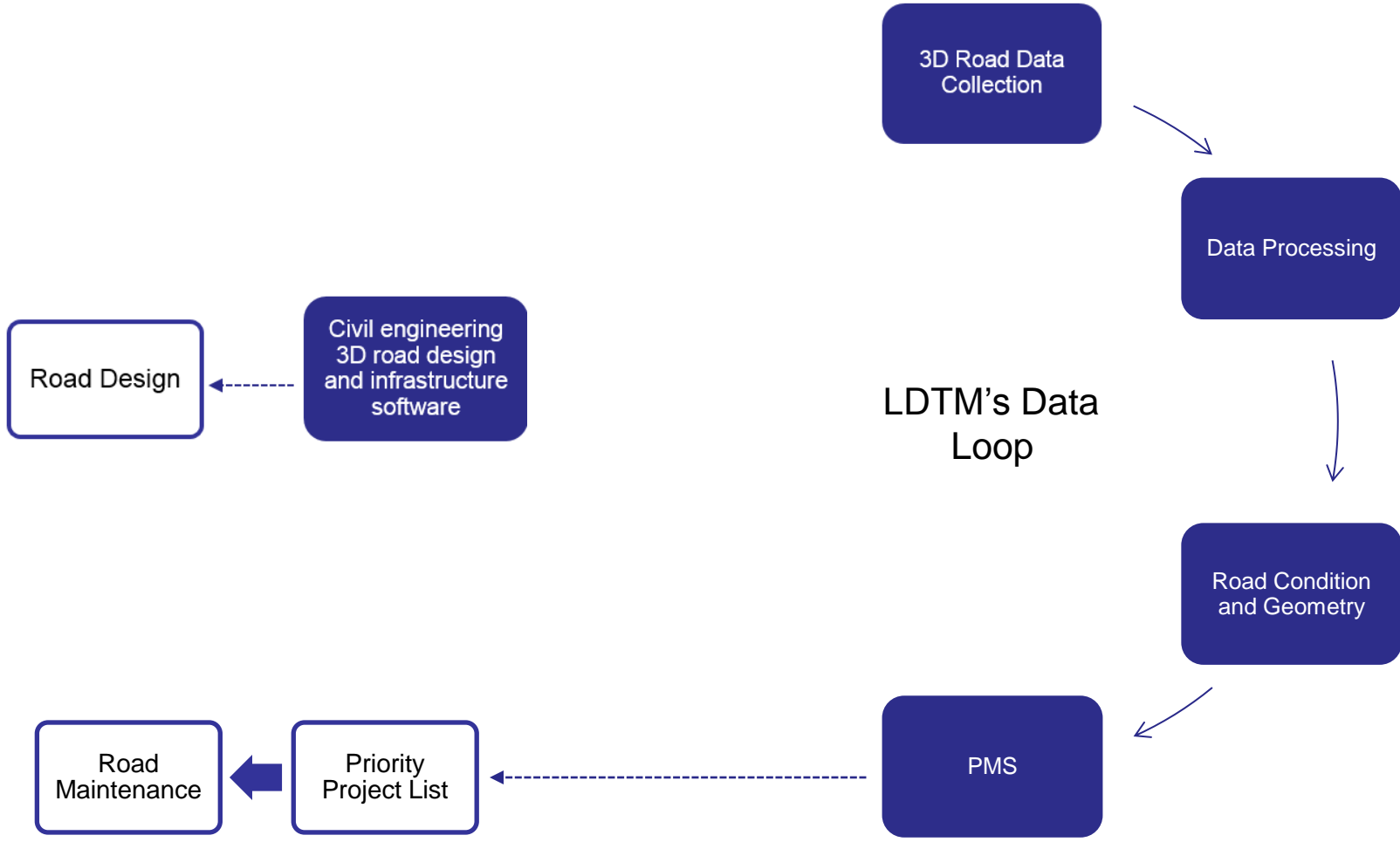
100% Inertial - 84m 2 known points

Scan	RMS Registrati	RMS Geometry preservation error (mm)			
		X	Y	Z	Module
2	3.12	2.07	3.07	2.38	4.40
3	4.26	2.08	3.09	5.30	6.48
4	5.73	5.18	4.63	4.14	8.09
5	4.51	3.37	4.03	3.62	6.38
6	3.21	2.00	3.80	2.66	5.05
Mean	4.17	2.94	3.72	3.62	6.08

LDTM – Closing the Loop



LDTM – Closing the Loop



Pavemetrics

Road Profile Before Corrections



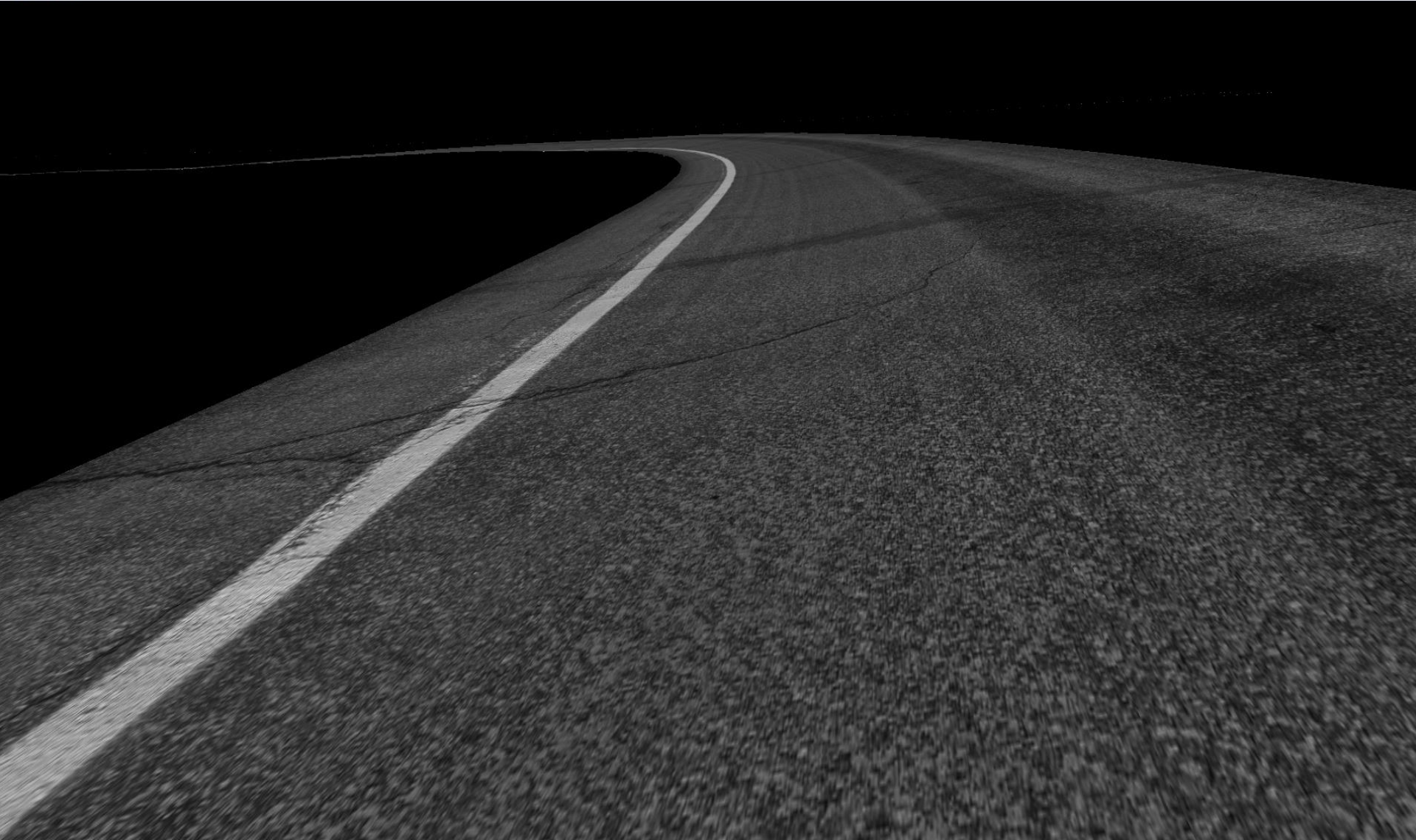
The logo for Pavemetrics, featuring the word "Pavemetrics" in a bold, sans-serif font. Below the text is a stylized graphic of a road with a dashed center line and a solid edge line, all contained within a white circular shape that is partially enclosed by a dark, curved border.

Pavemetrics

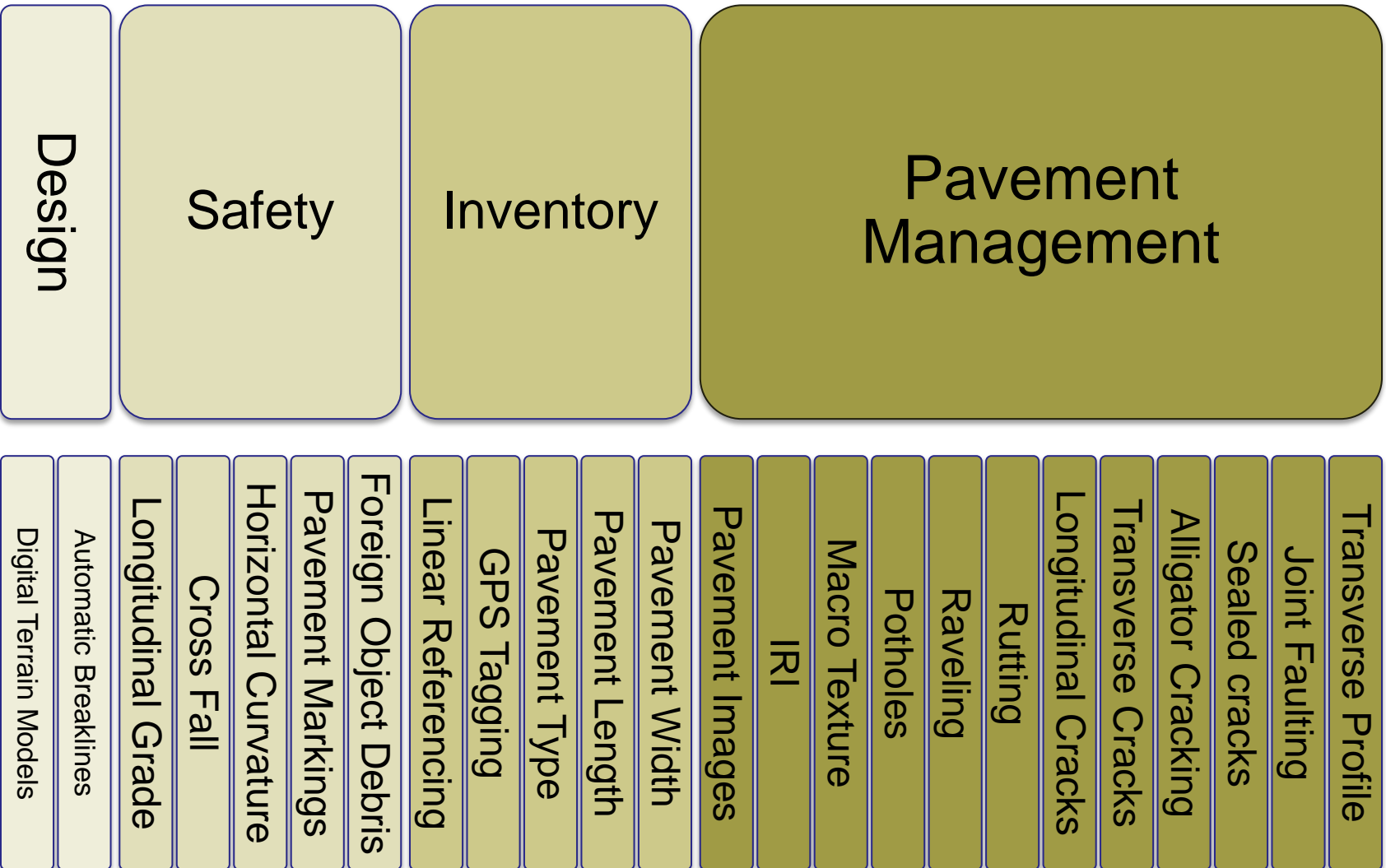
Road Profile After Geometric and Dynamic Corrections

D:\Temp\LcmsData\2013_07_31\Acqui_0010_LastPart\LcmsData_001965.fis - LcmsPV3D

File View Help



One Sensor; Many Outputs



Pavemetrics

Any Questions?

D:\Temp\LcmsData\2013_07_31\Acqui0010\LcmsData_000000.fis - LcmsPV3D

File View Help



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