LCMS – Laser Crack Measurement System

Pavemetrics

Vision Technology for Inspection of Transportation Infrastructures

PAVEMETRICS Systems Inc.

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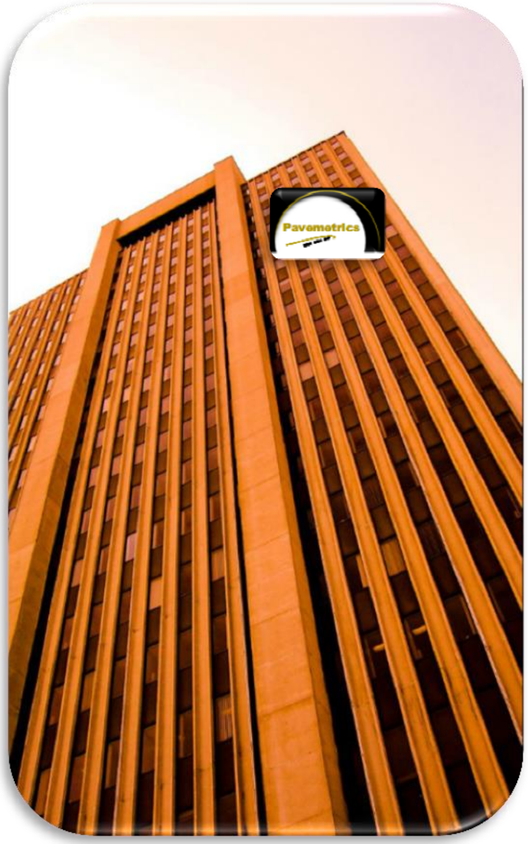
Québec, Québec, CANADA
G1R 5B1

www.pavemetrics.com

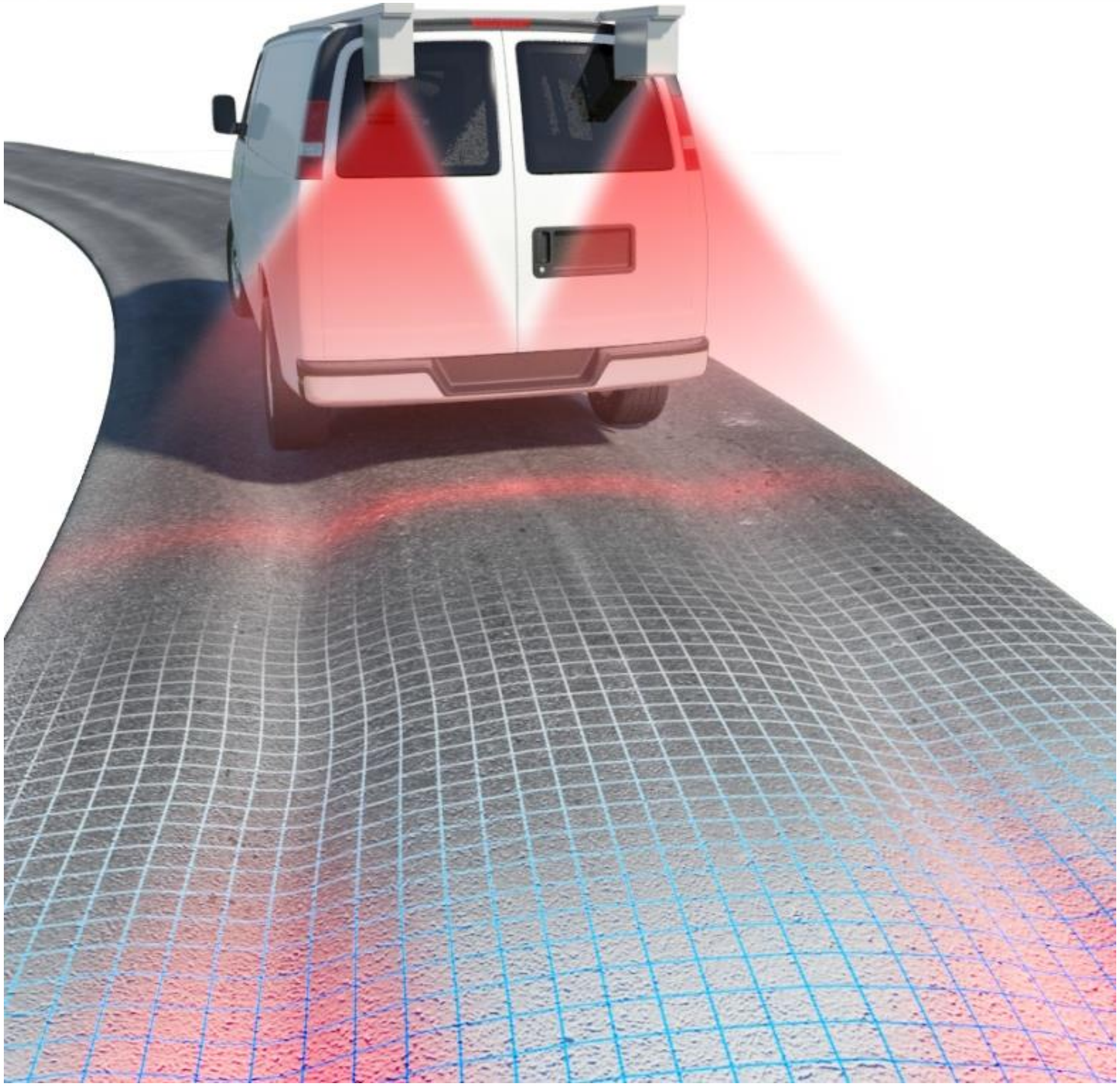
Pavemetrics; Infrastructure Vision Systems Specialists



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**

Application: ROADS distress and DTM



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The Sensor Technology Most Relied-on by DOTs worldwide

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Collect Your Own, or Contract-out

ARRB Group

Stantec

Fugro

Ramboll

Mandli Communications Inc

International Cybernetics — Where technology meets the road

romdas

Vectra France

Euroconsult Nuevas Tecnologías

CenterInfo

Dynatest® — Pavement engineering specialists & equipment

LVM

SNC-Lavalin

LCMS – Certified Technology

NOT a prototype

Certified AND proven around the world.

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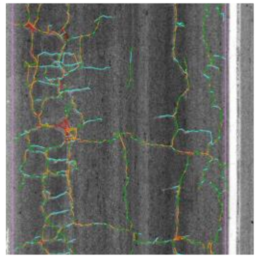
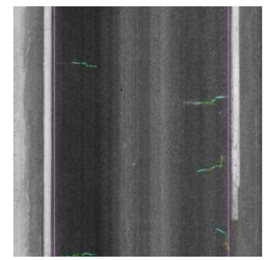
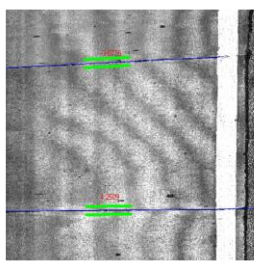
Any Paved Surface



Hotmix

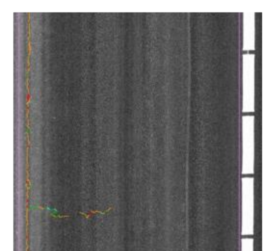
Chipseal





Concrete

Porous



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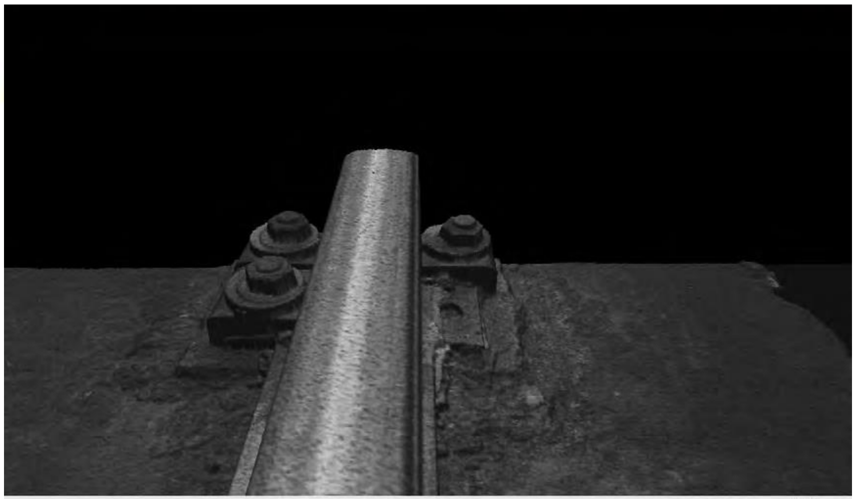
APPLICATION: Rails



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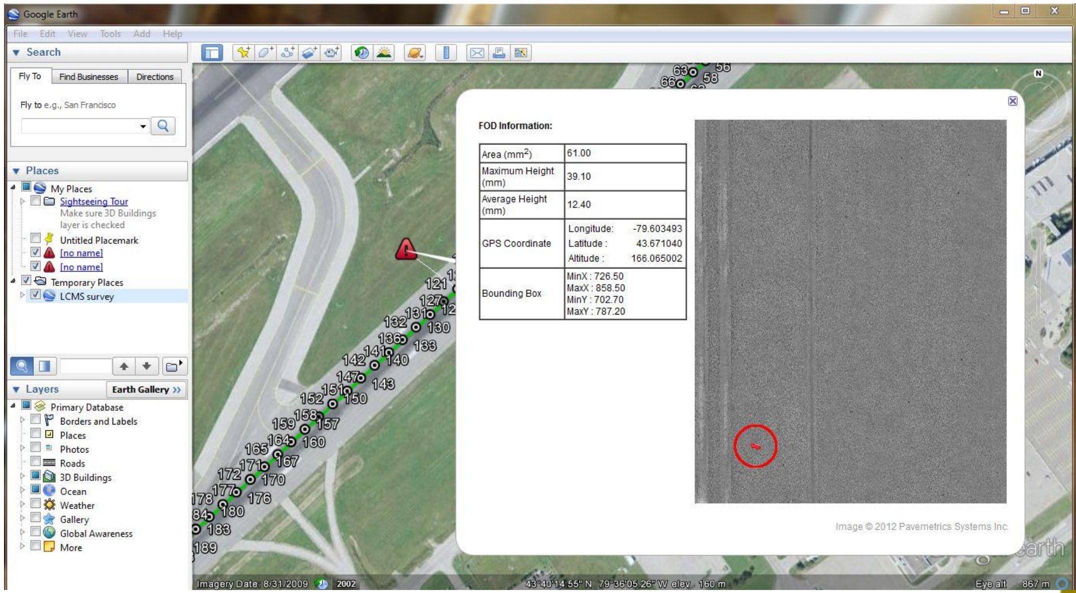
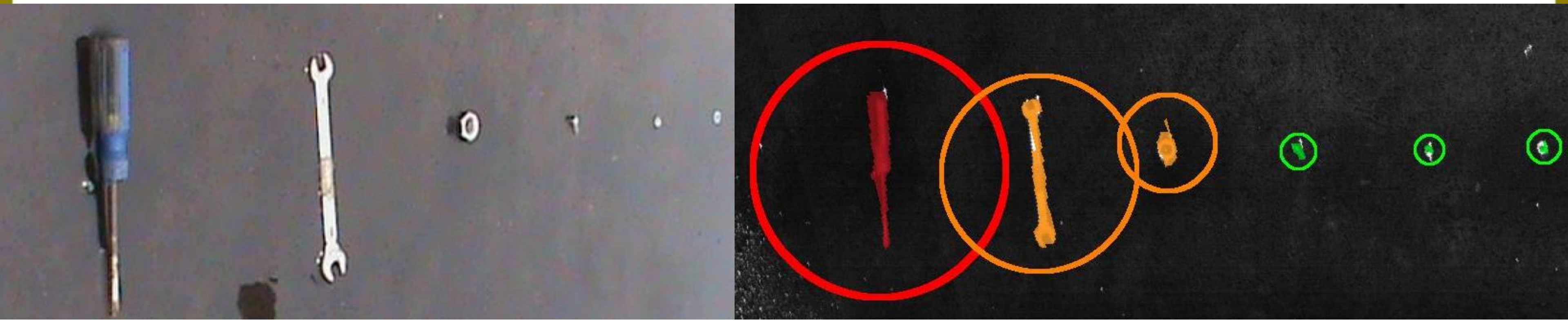
APPLICATION: Tunnels

Pavemetrics

Application: Airports - FOD





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Runways currently scanned with Pavemetrics Technology

Abu Dhadi (AUH)

Bahrain (BAH)

Barcelona (BCN)

Doha (DOH)

Dubai (DBX)

Gatwick (LGW)

Heathrow (LHR)

Los Angeles (LAX)

Mirabel (YMX)

Oman (MCT)

Roma (FCO)

Saint-Louis (STL)

Schiphol (AMS)

Singapore (SIN)

Utah (32 airports)

…

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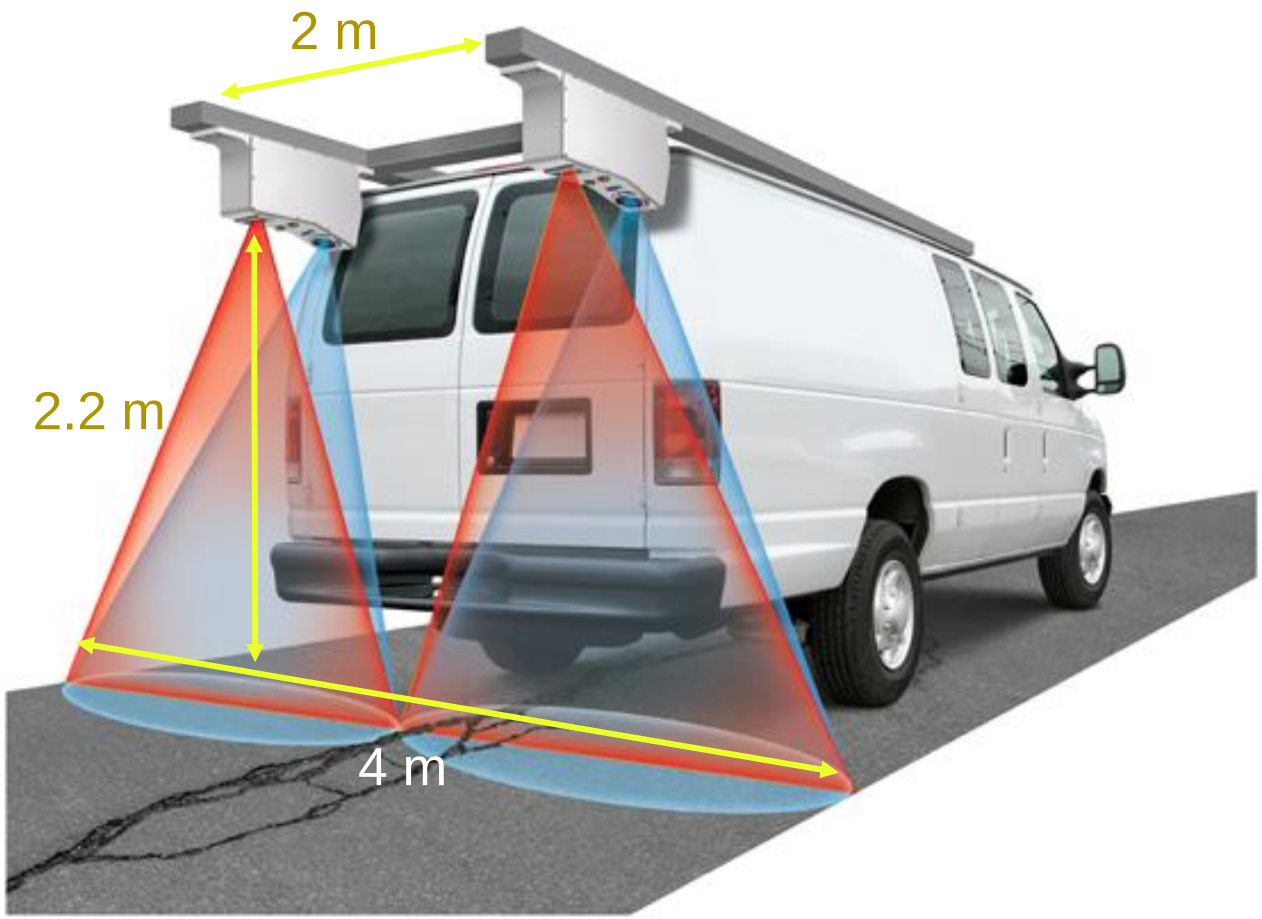
LCMS - System configuration



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Laser profiling (principle)

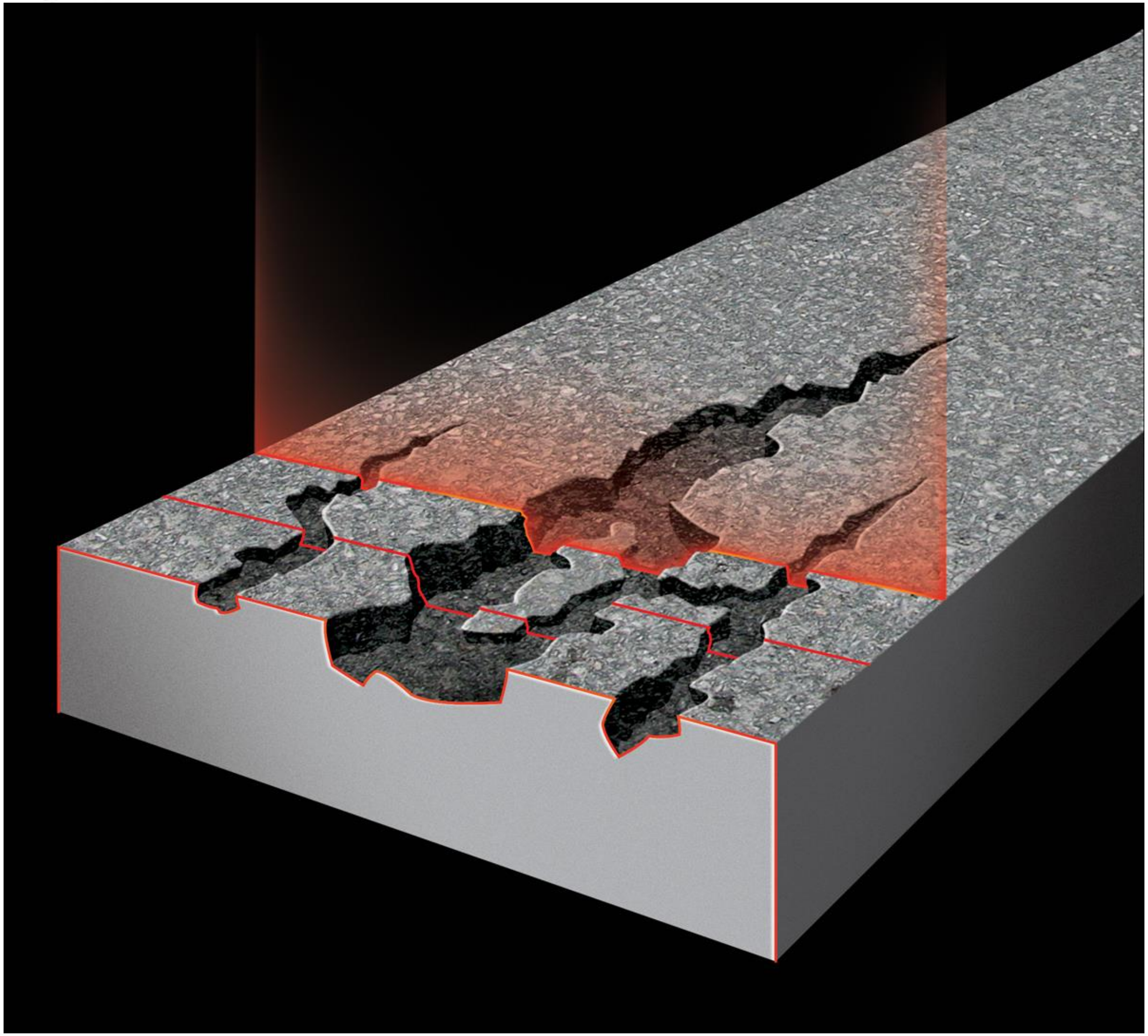
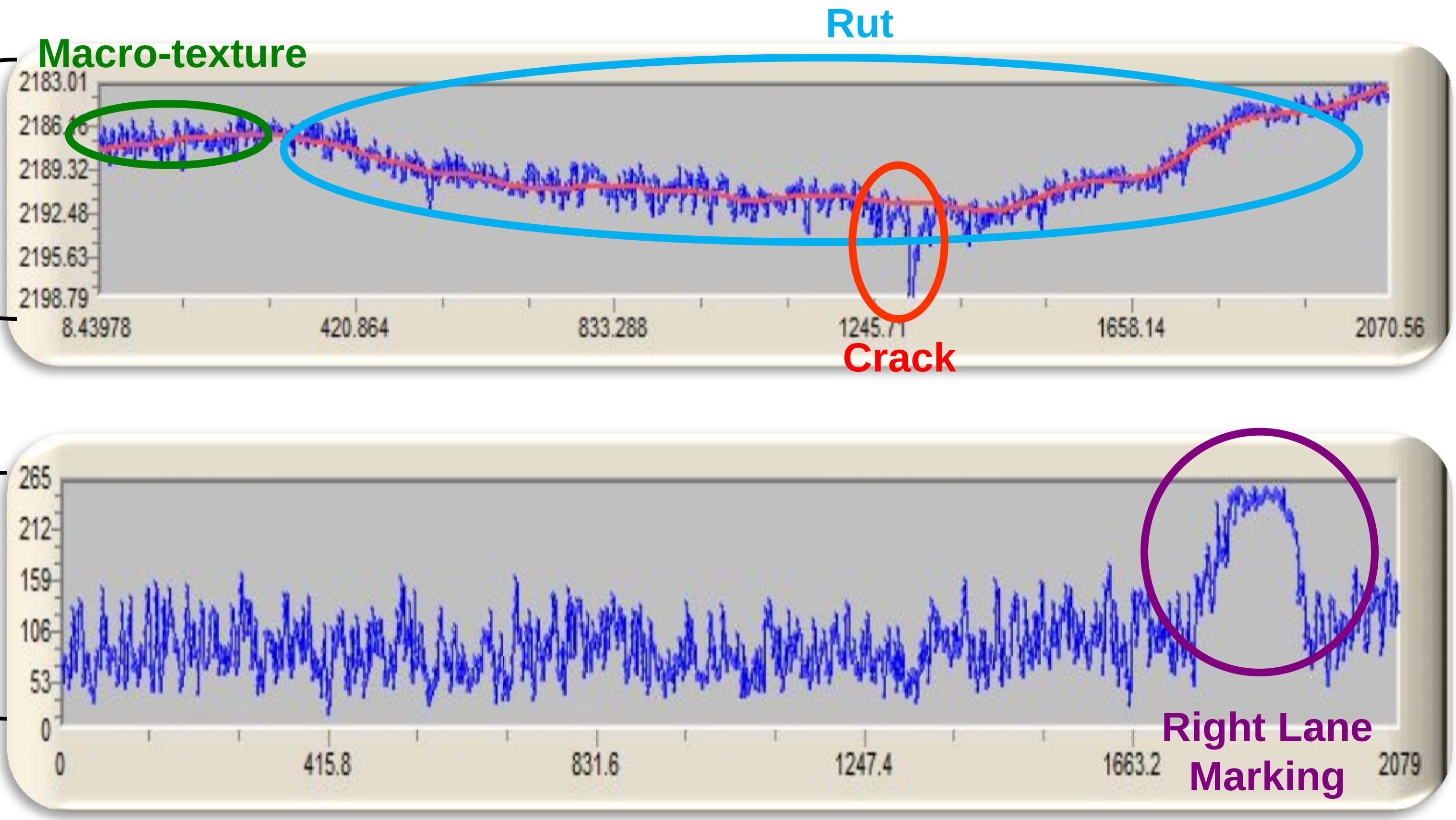


Image and Data Analysis

RANGE
Distance between Sensor and ground (in mm)

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



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2D Versus 3D Technology

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…**

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Real?

http://www.julianbeever.net/

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2D Versus 3D Technology

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

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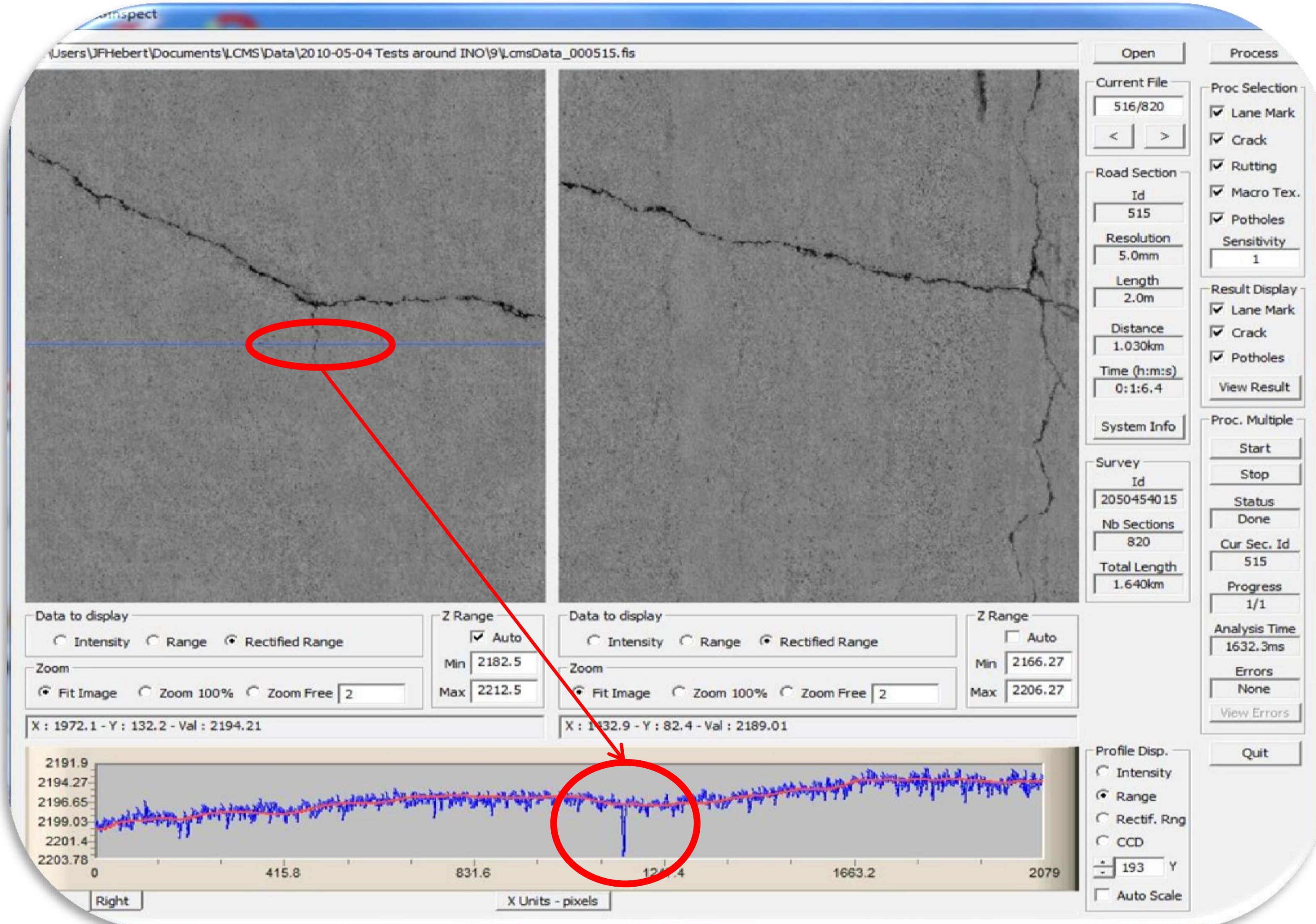
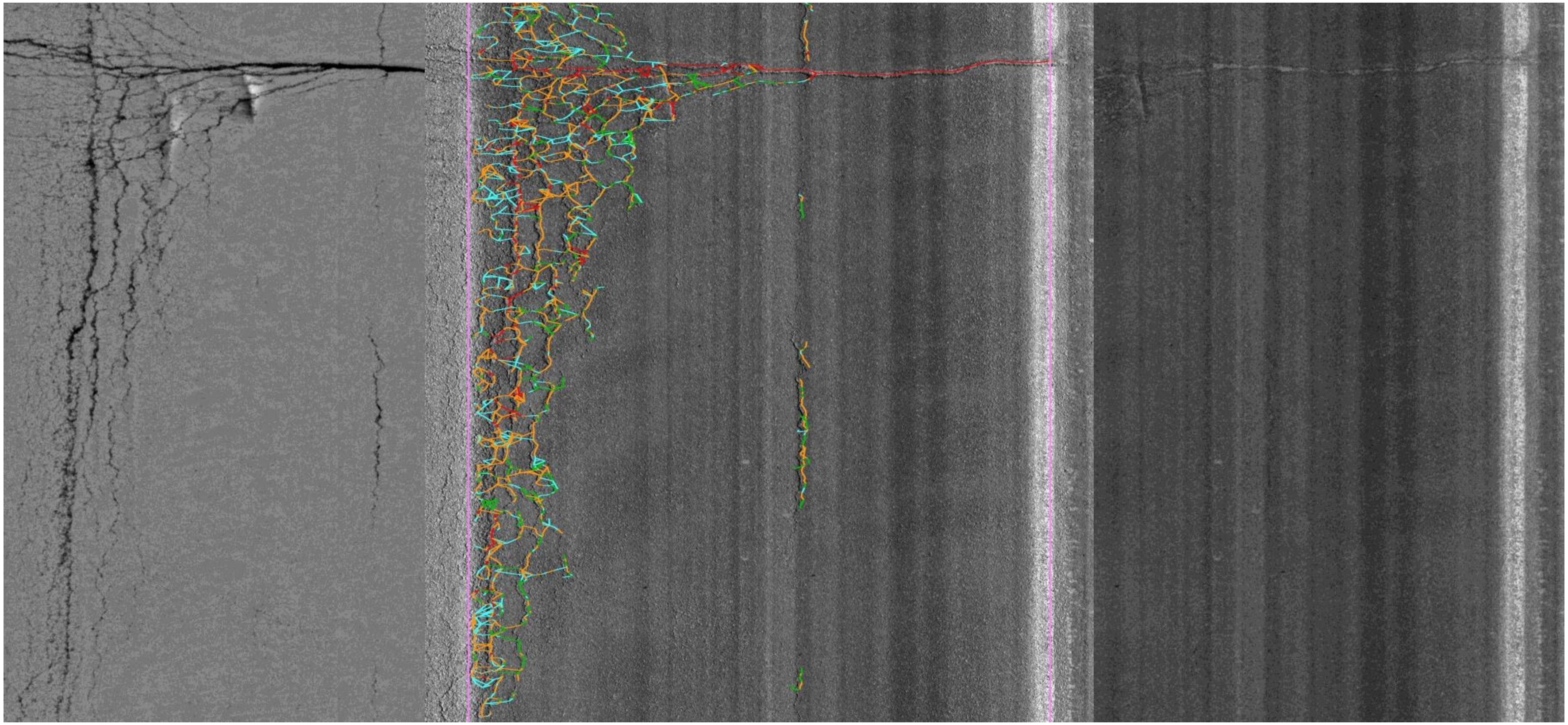
Real!



Understanding 3D Imaging



Range **Merged** **Intensity**

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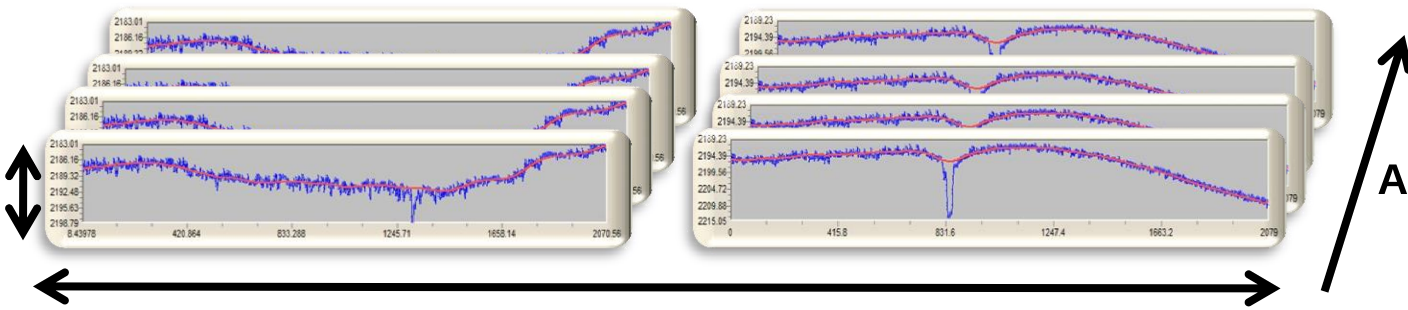
LCMS - Specifictions

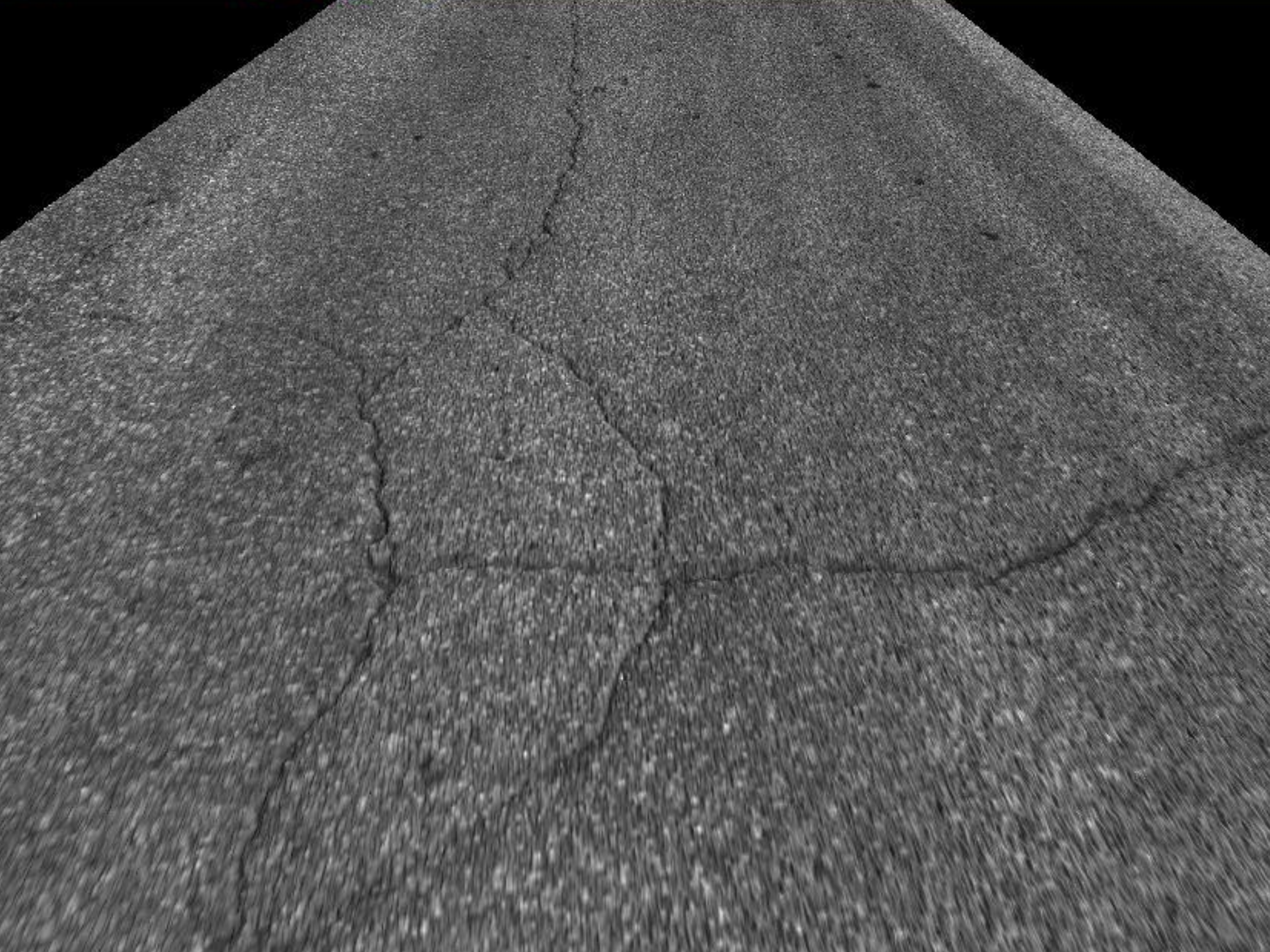
Excellent 3D Accuracy

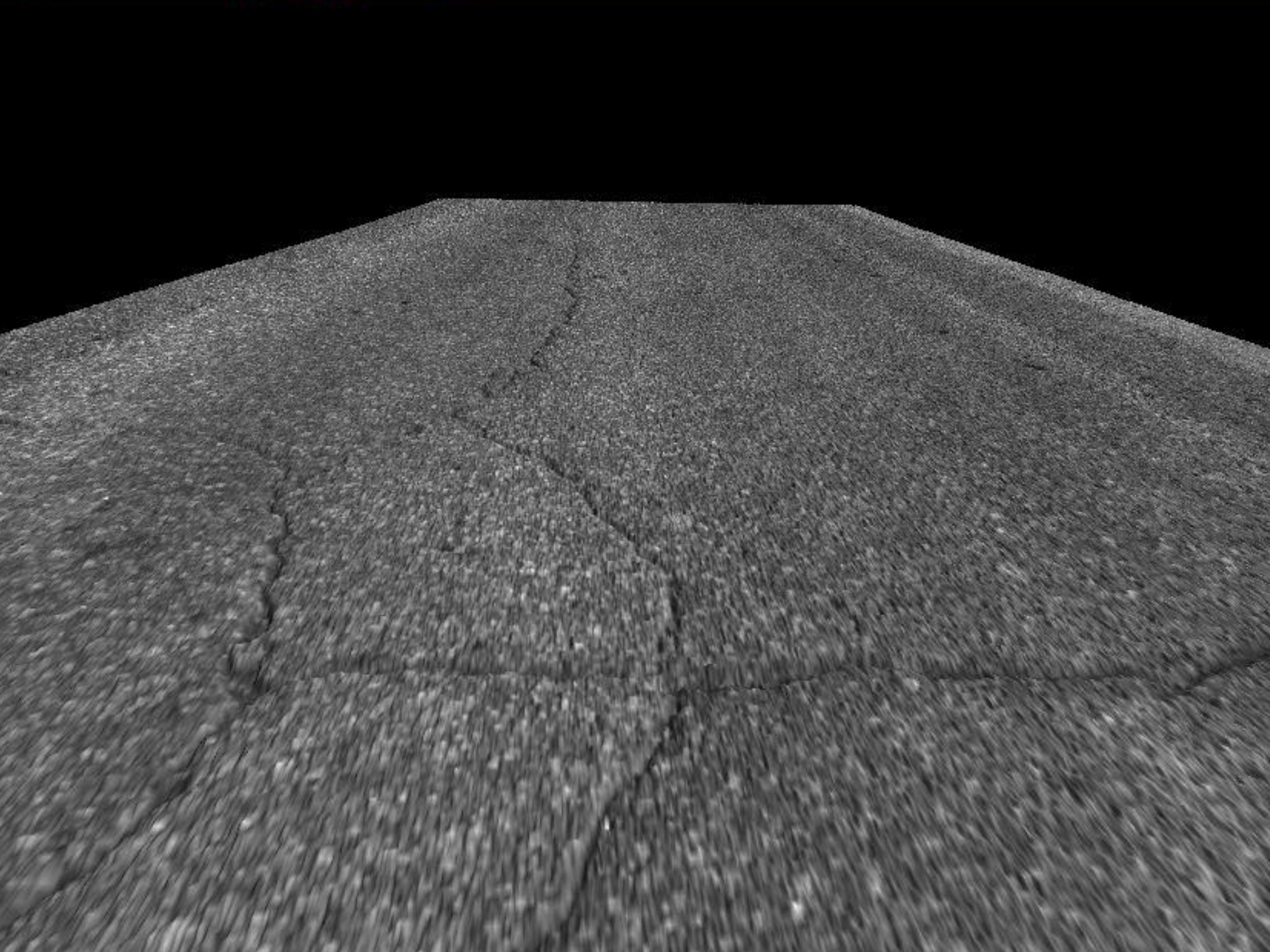


High Acquisition Rate

Sufficient Lateral Resolution

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 !

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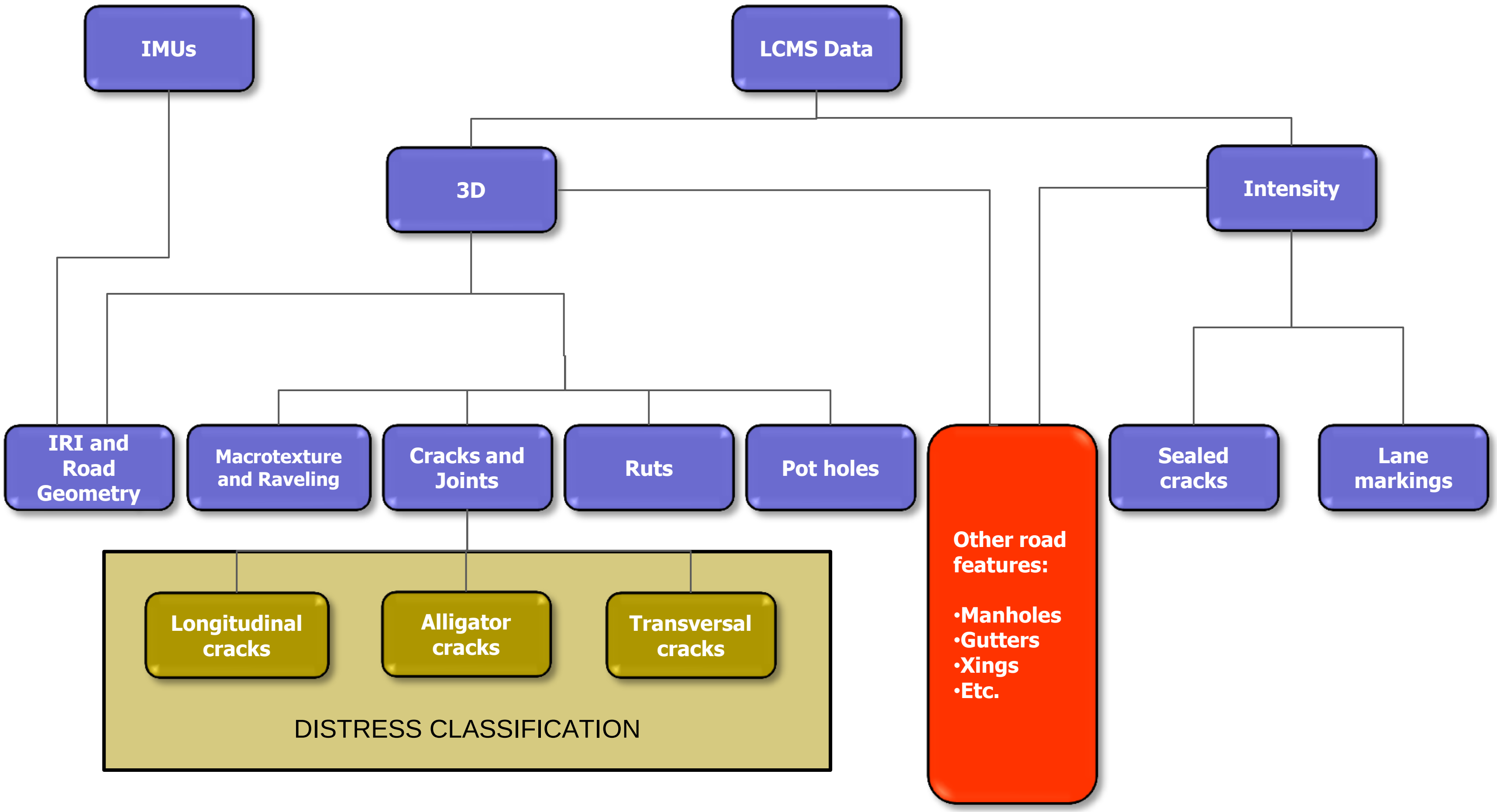
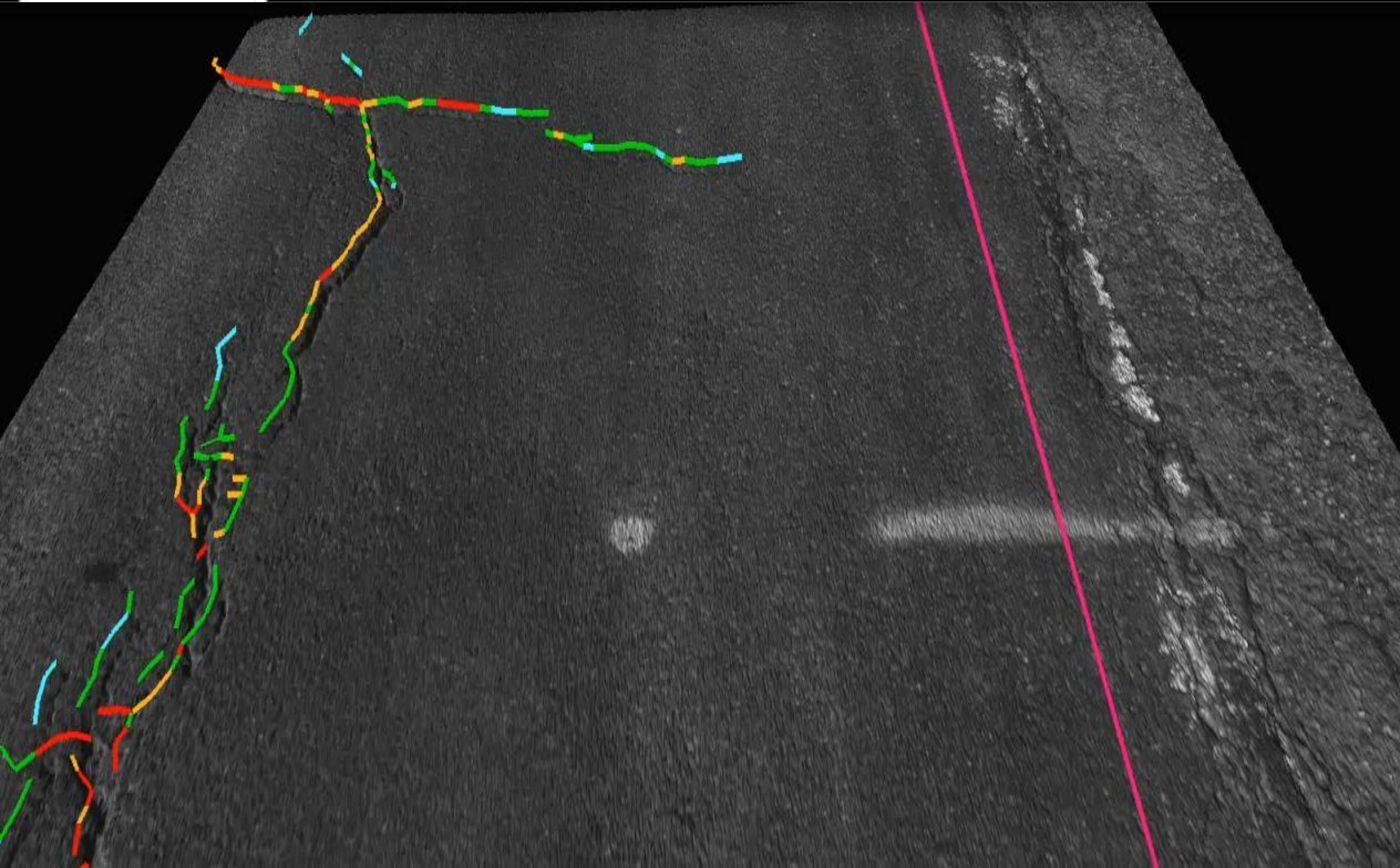
LCMS Data Processing Tree

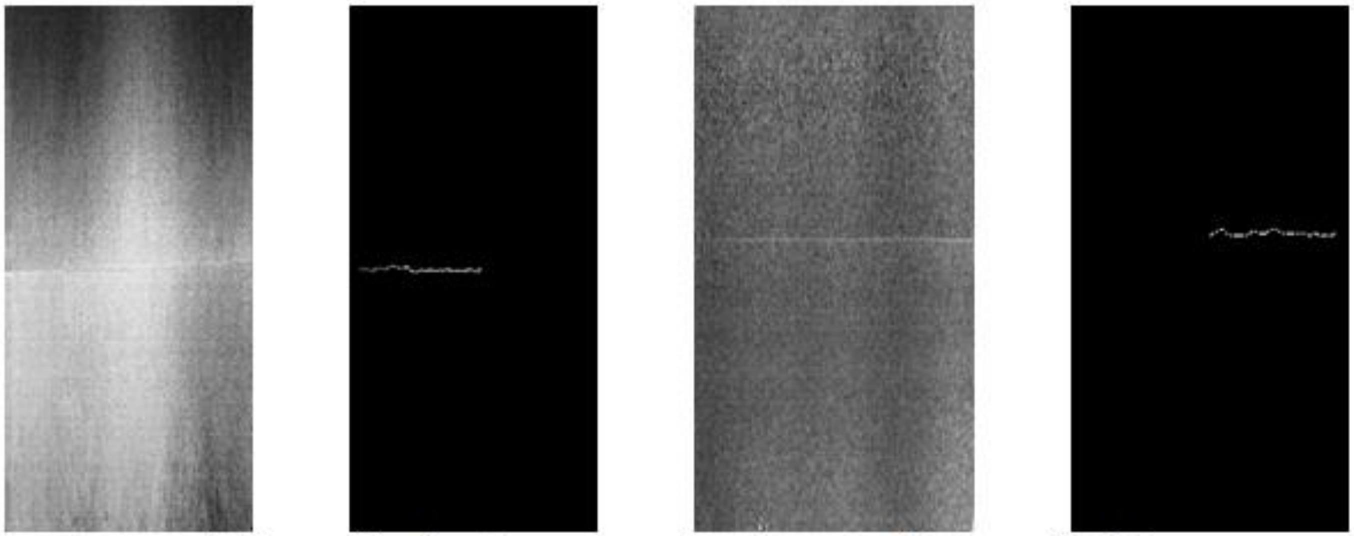


Crack Detection

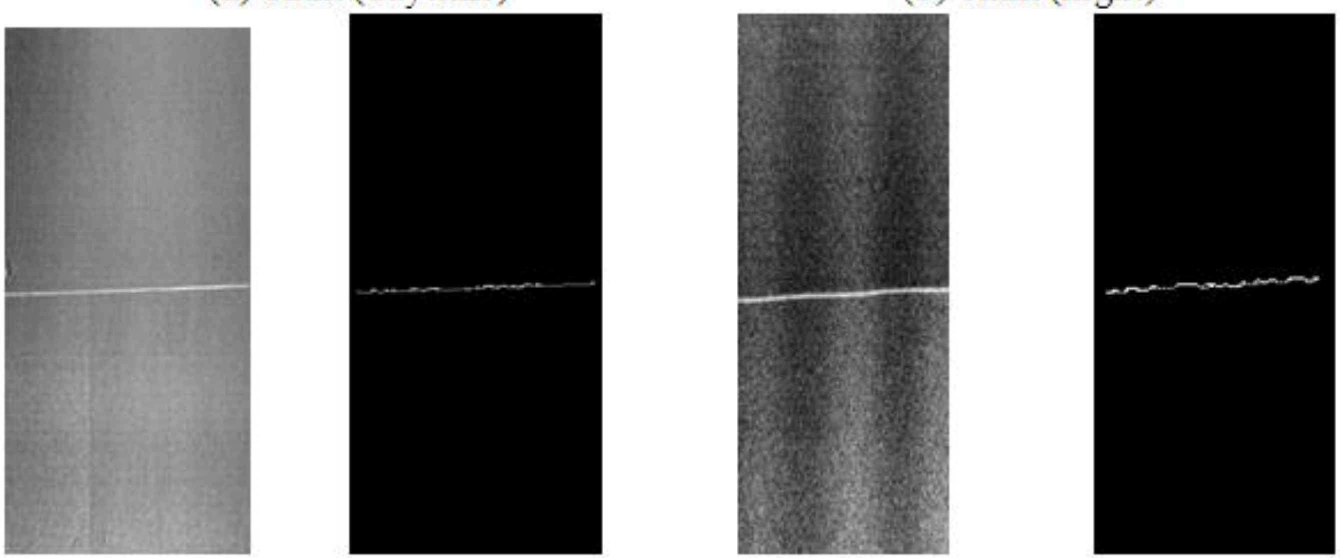
Edge Dropoff Detection



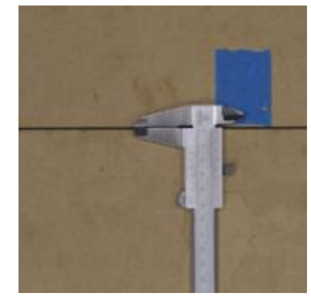
LCMS crack detection tests



(a) 1mm (daytime) (b) 1mm (night)

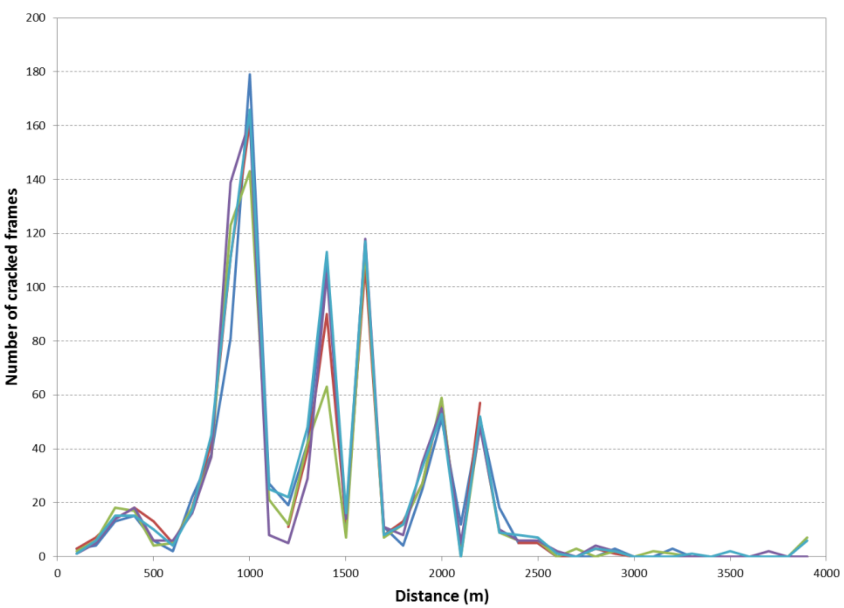


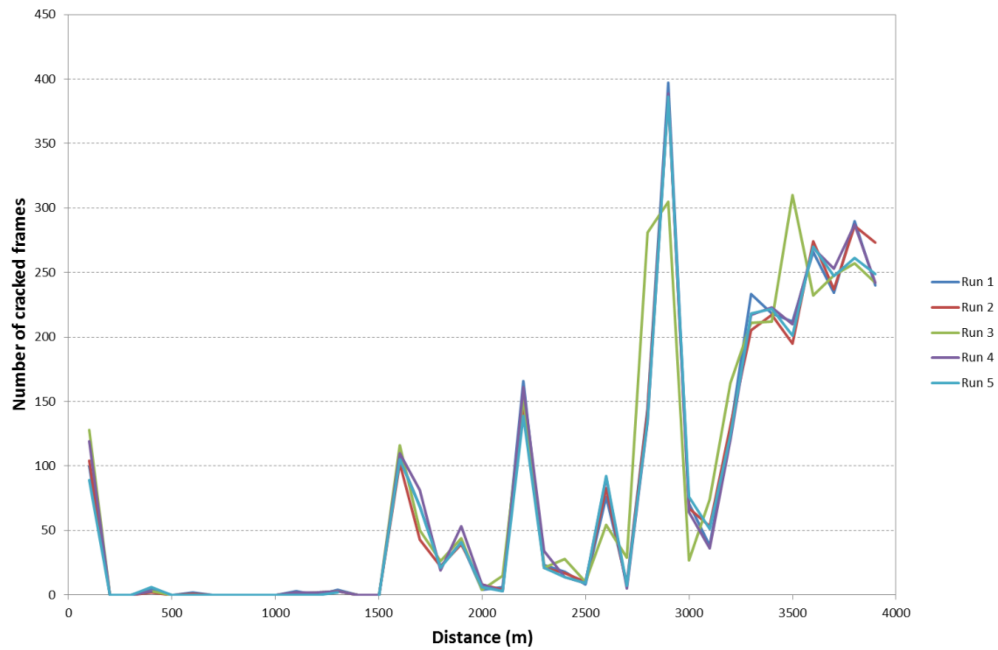
(c) 2mm (daytime) (d) 2mm (night)



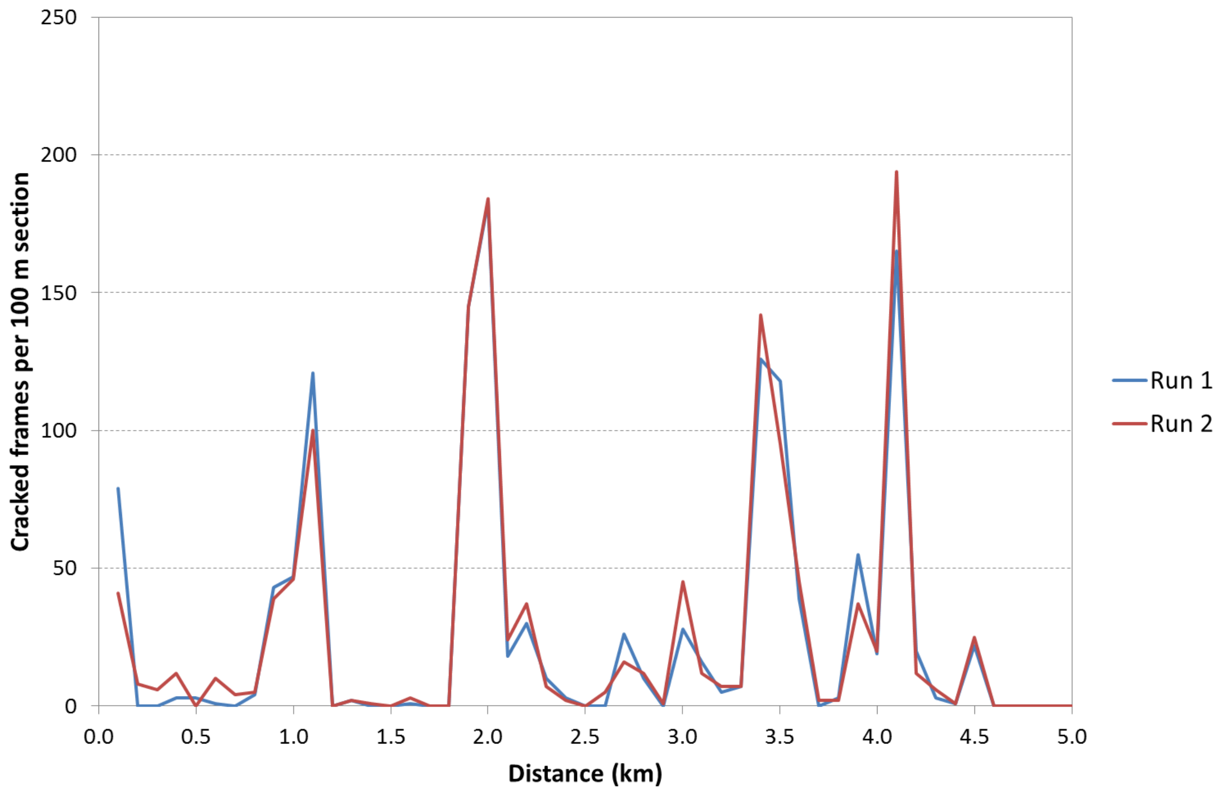
LCMS repeatability DGA test site – ARRB - Australia

		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)



Network level testing 6000mi Summer 2008

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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

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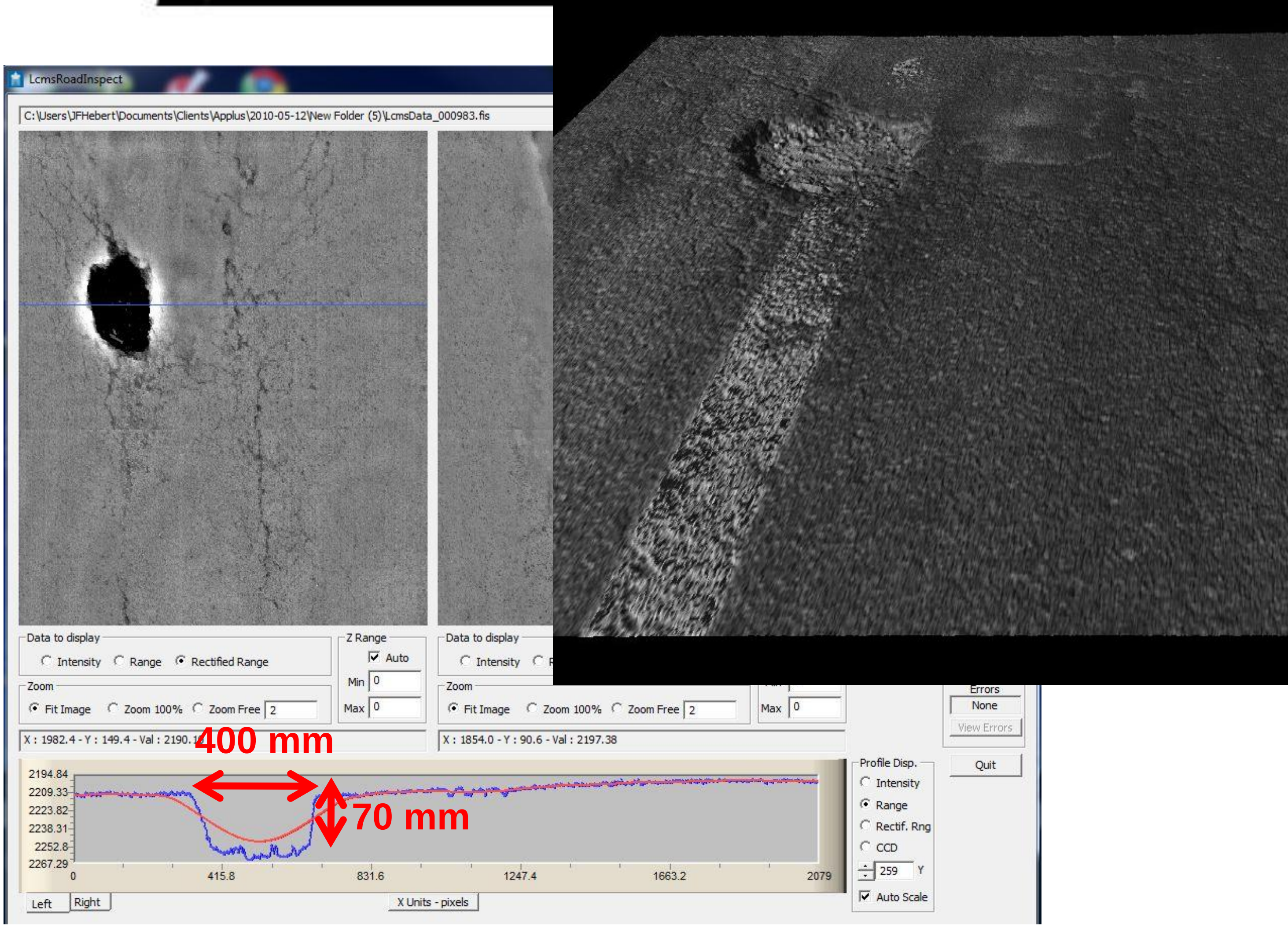
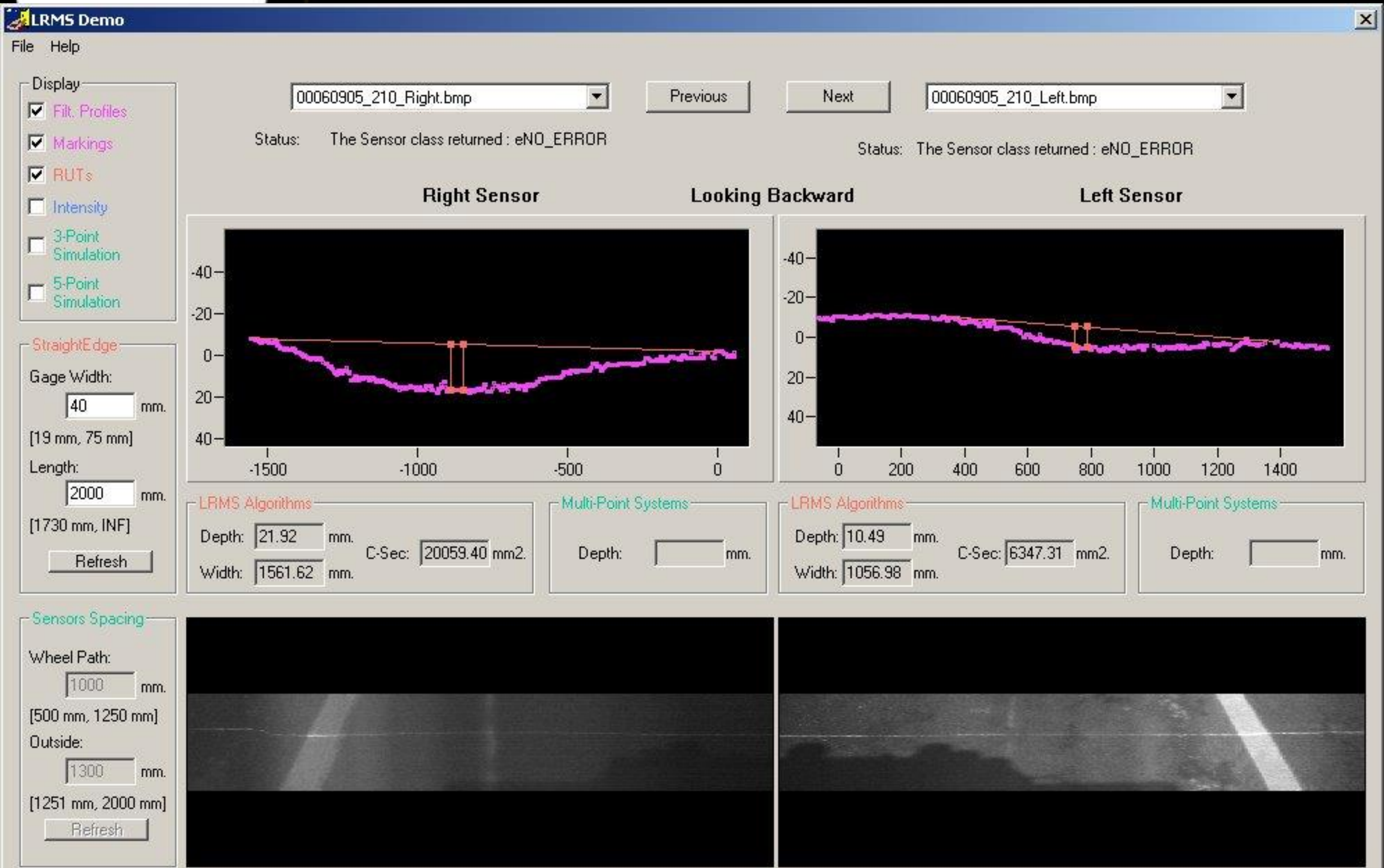
Pothole Detection



Example


LRMS Demo
File
Help
Display
Filt. Profiles
Markings
RUTs
Intensity
3-Point Simulation
5-Point Simulation
StraightEdge
Gage Width:
40
mm.
[19 mm, 75 mm]
Length:
2000
mm.
[1730 mm, INF]
Refresh
Sensors Spacing
Wheel Path:
1000
mm.
[500 mm, 1250 mm]
Outside:
1300
mm.
[1251 mm, 2000 mm]
Refresh
00060905_210_Right.bmp
Previous
Next
00060905_210_Left.bmp
Status: The Sensor class returned : eNO_ERROR
Status: The Sensor class returned : eNO_ERROR
Right Sensor
Looking Backward
Left Sensor
-40
-20
0
20
40
-1500
-1000
-500
0
-40
-20
0
20
40
0
200
400
600
800
1000
1200
1400
LRMS Algorithms
Depth: 21.92 mm.
Width: 1561.62 mm.
C-Sec: 20059.40 mm2.
Multi-Point Systems
Depth: mm.
LRMS Algorithms
Depth: 10.49 mm.
Width: 1056.98 mm.
C-Sec: 6347.31 mm2.
Multi-Point Systems
Depth: mm.

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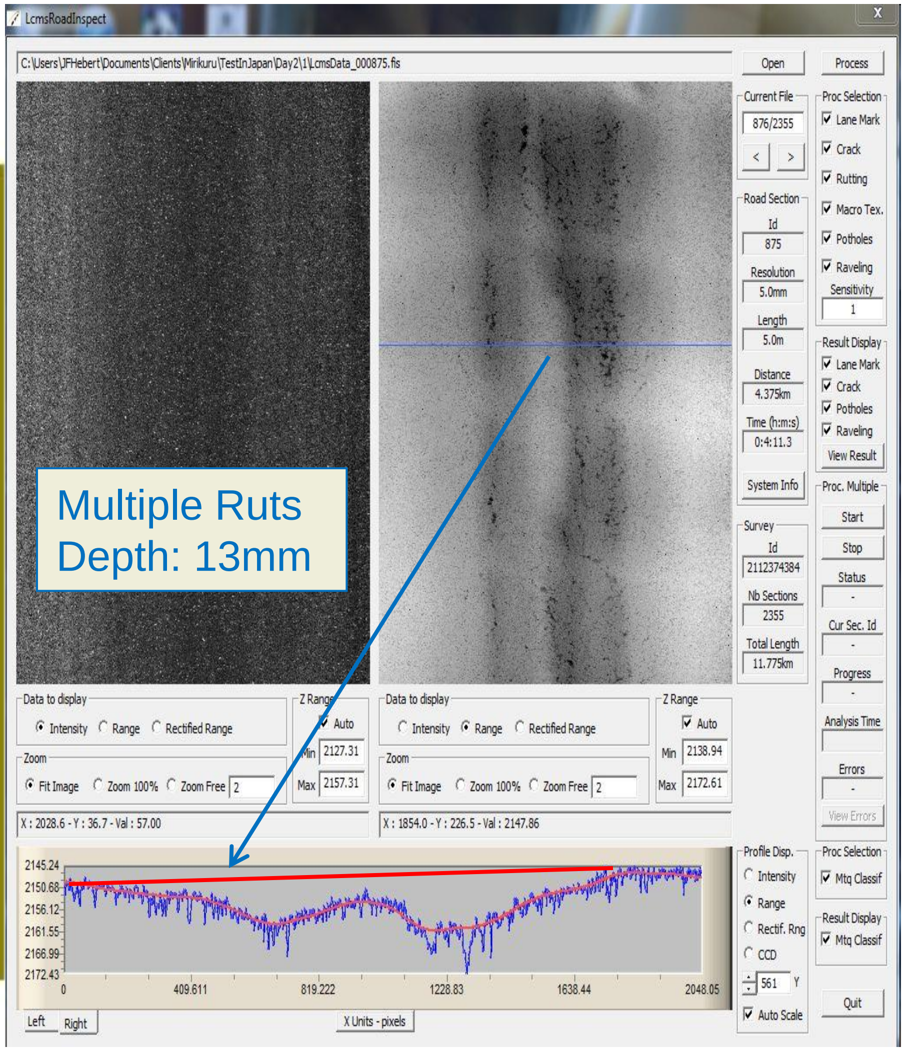
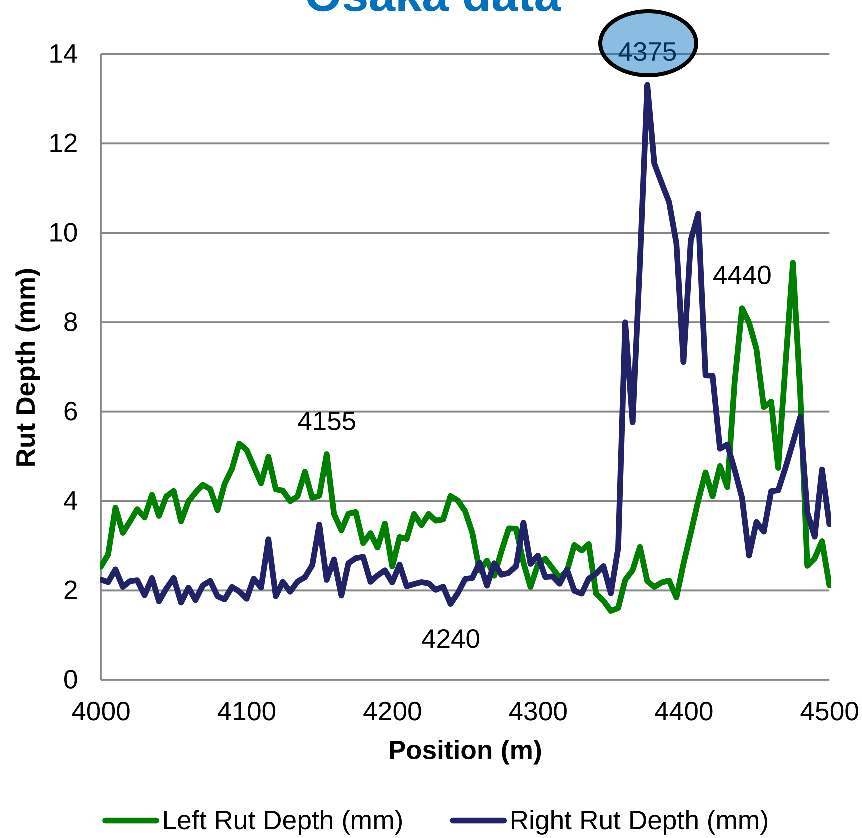
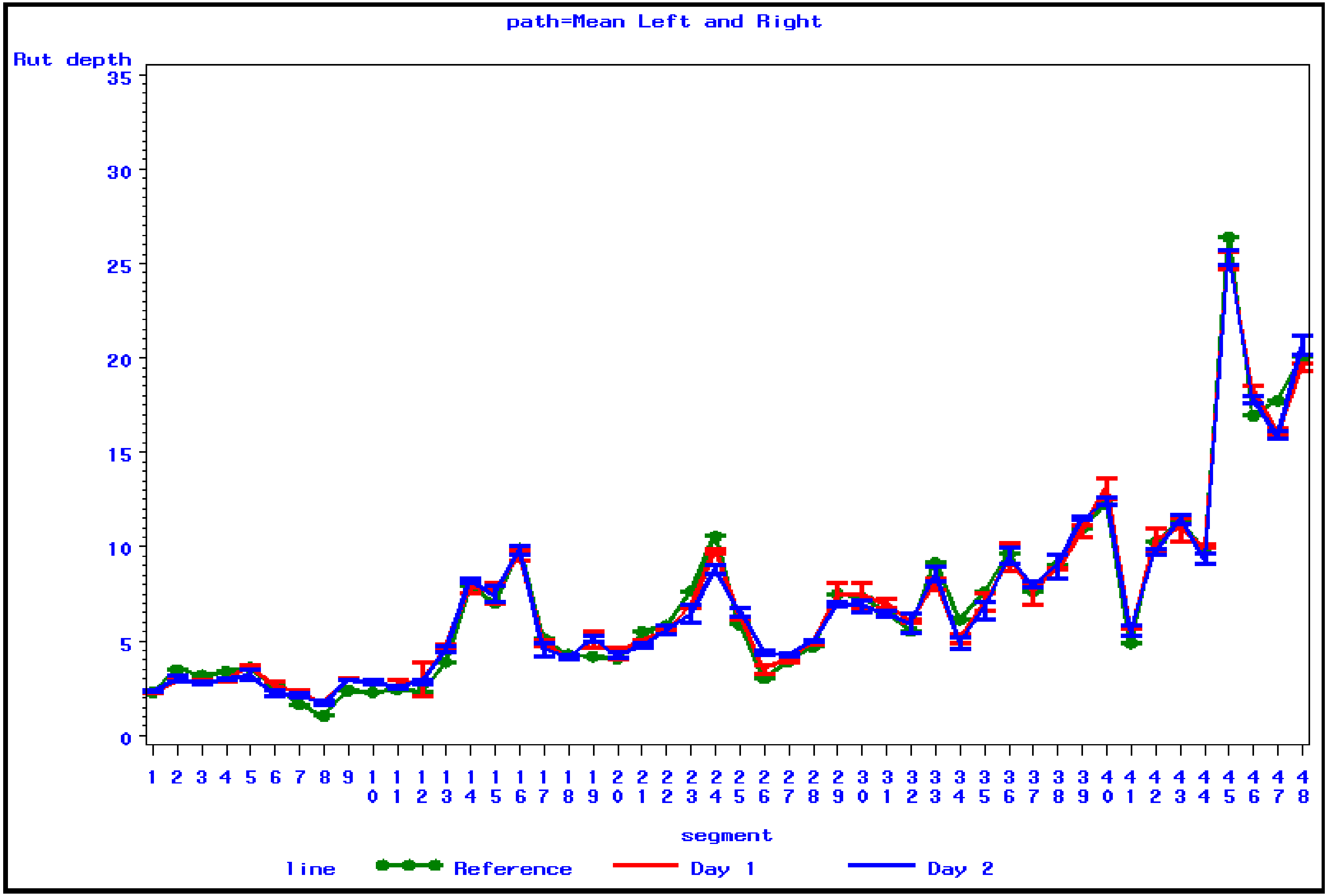
Rutting (depth, width, type)



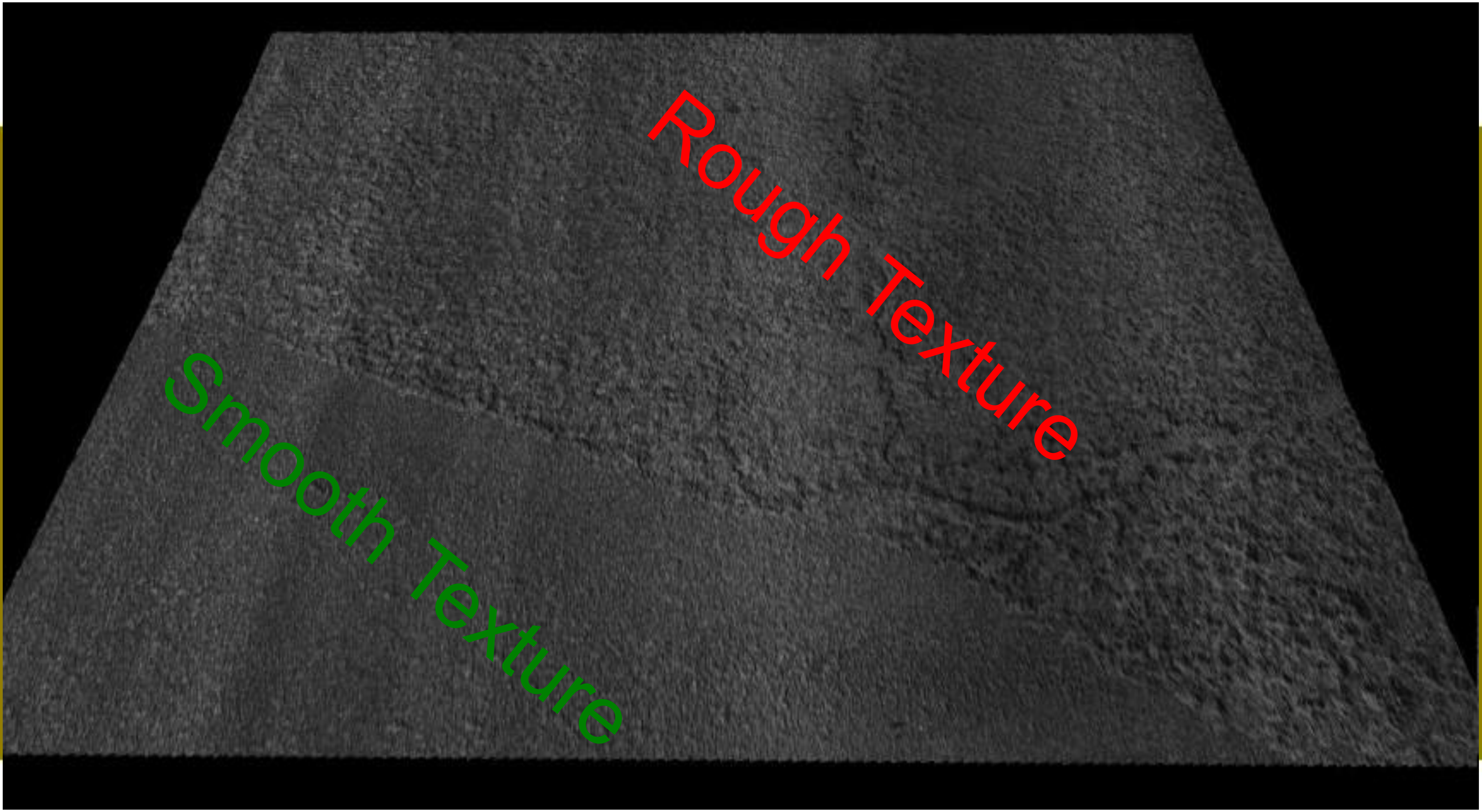
Rut Depth (per road section) between 4.0km and 4.5km for Osaka data



MTQ validation – 100 m intervals (48 sections)



Macrotexture



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.

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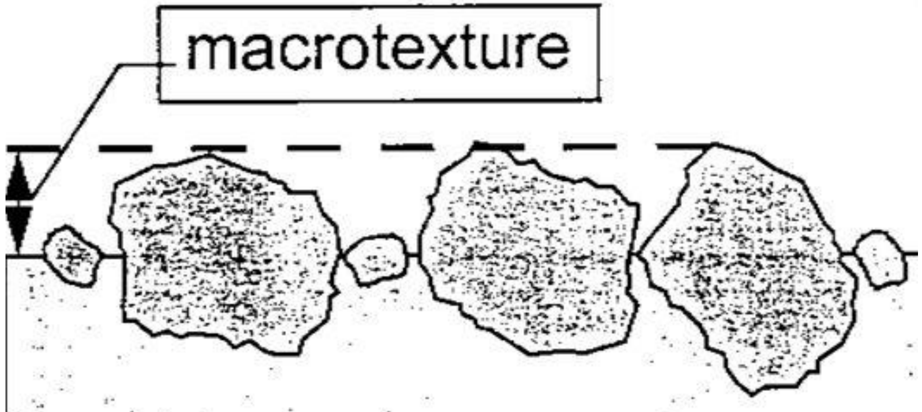
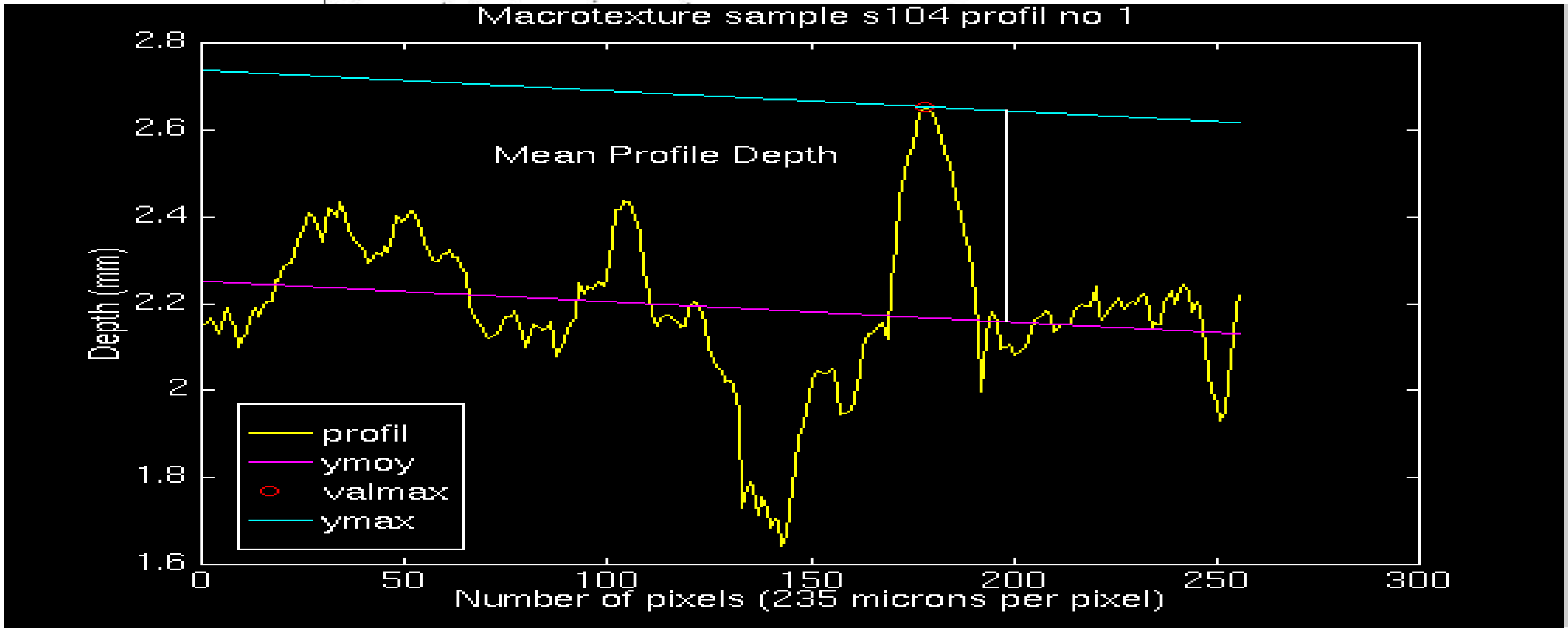
Macrotexture : Mean Profile Depth (ASTM E1845-01)





Single Road Profile (2 meter)

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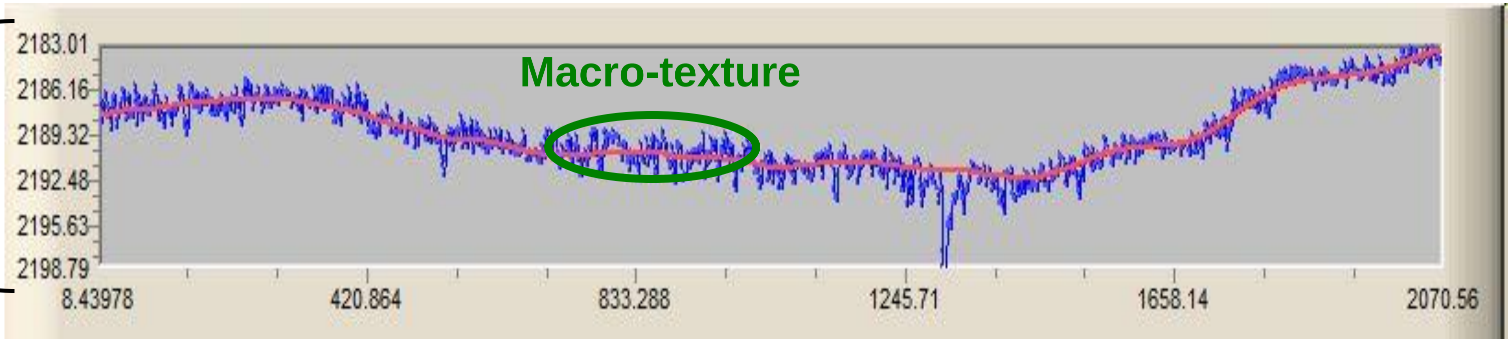
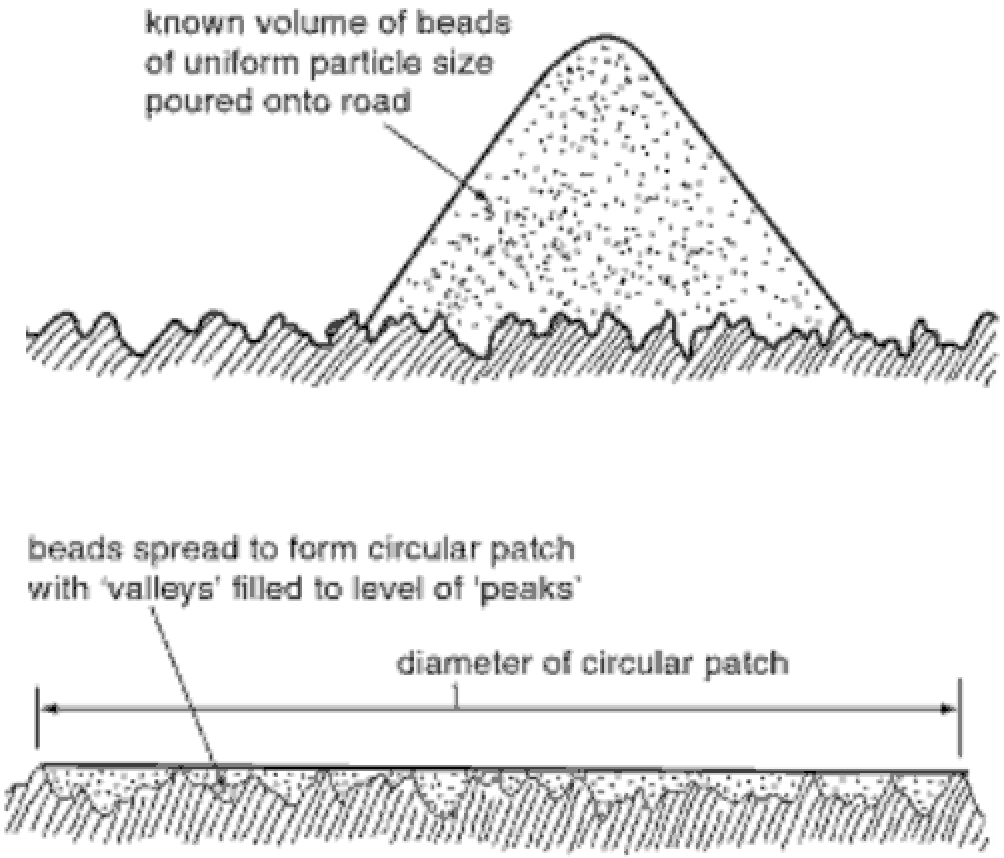
Distance between Sensor and ground (in mm)

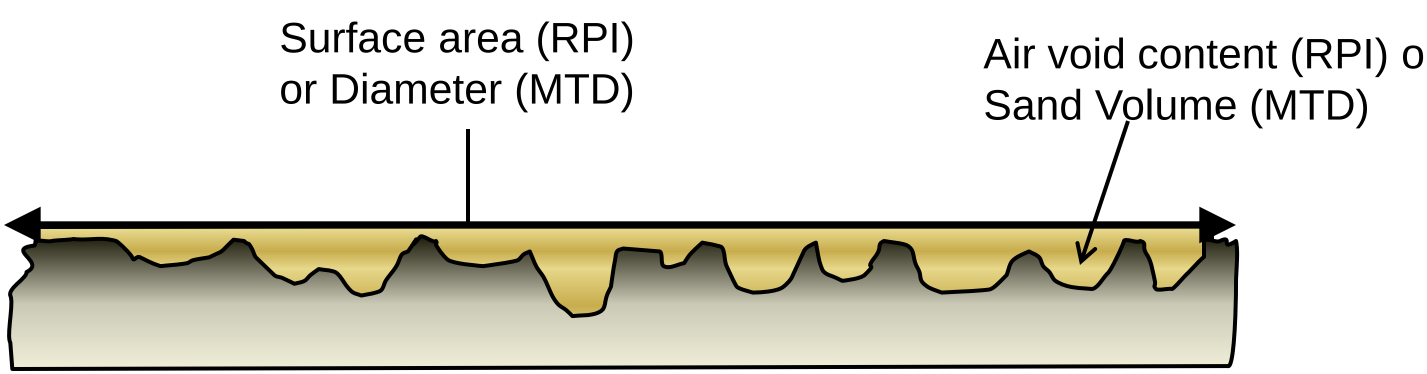


Macrotexture : Sand patch method (MTD) (ASTM E965)



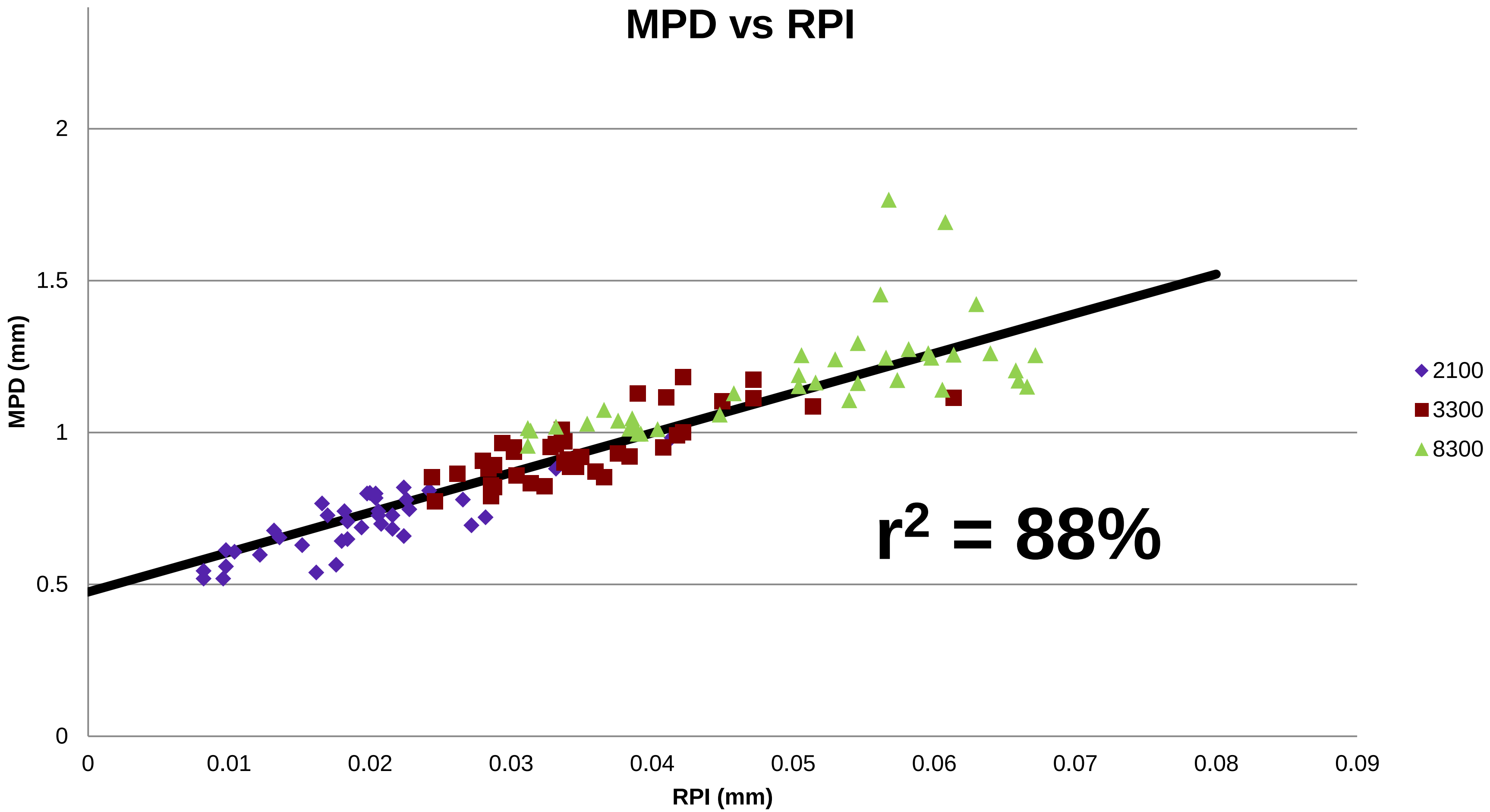
Macrotexture – RPI
Digital Sand Patch Method

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

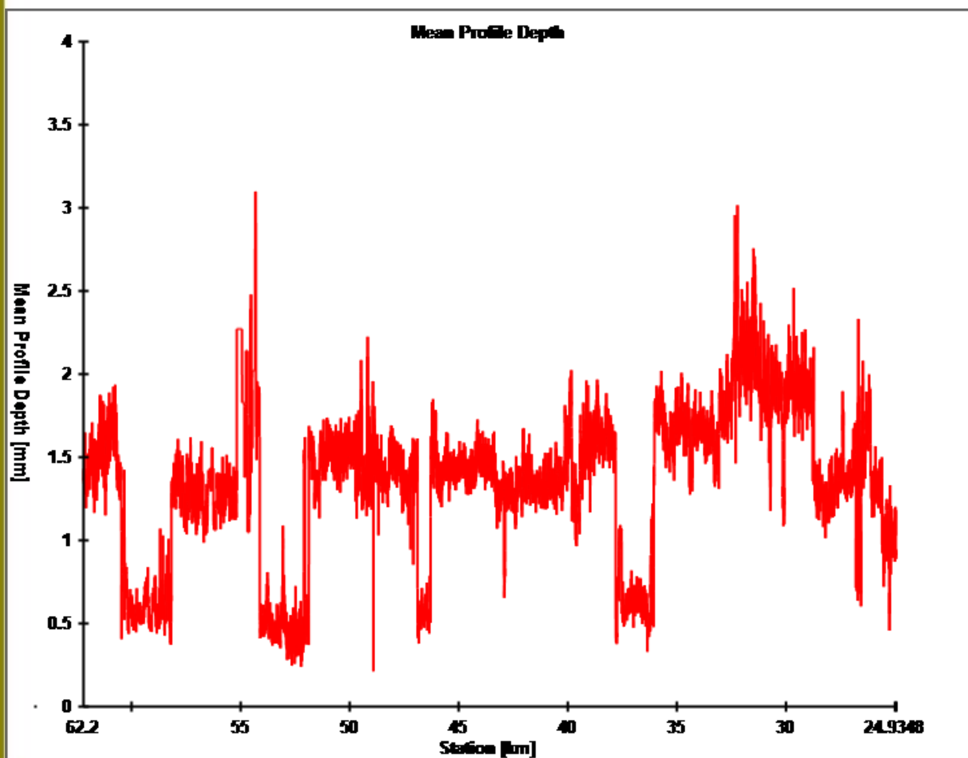


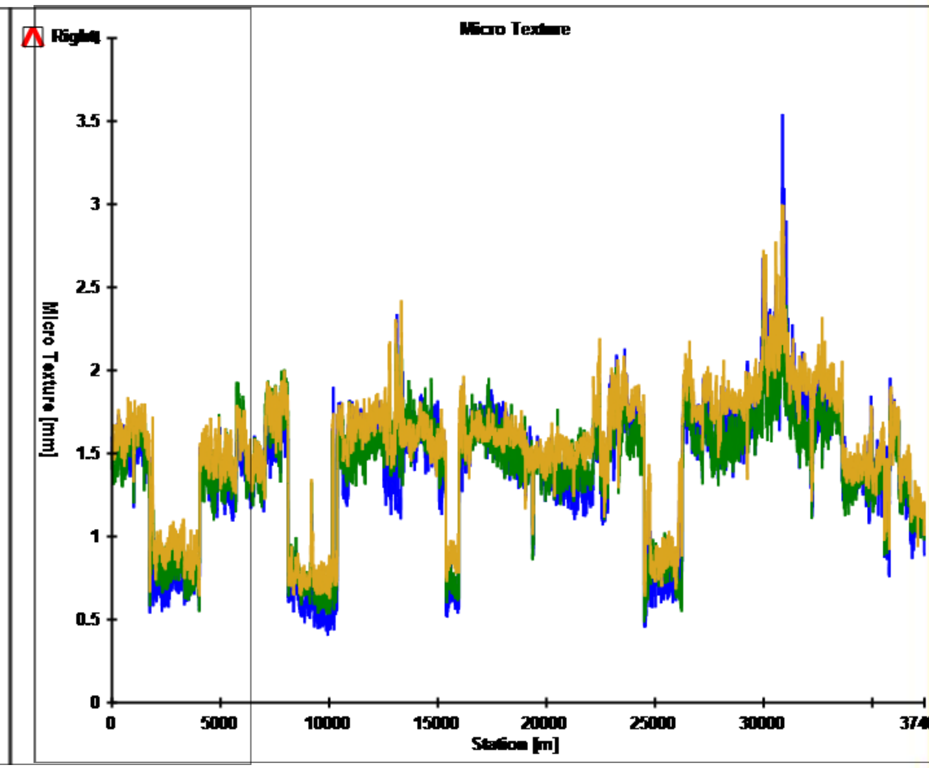
$$RPI = \frac{(Vol_{air\ void} - Vol_{pothole} - Vol_{cracks})}{Area_{Total}}$$

Macrotexture – Correlation between MPD and RPI



LCMS vs 64 KHz laser





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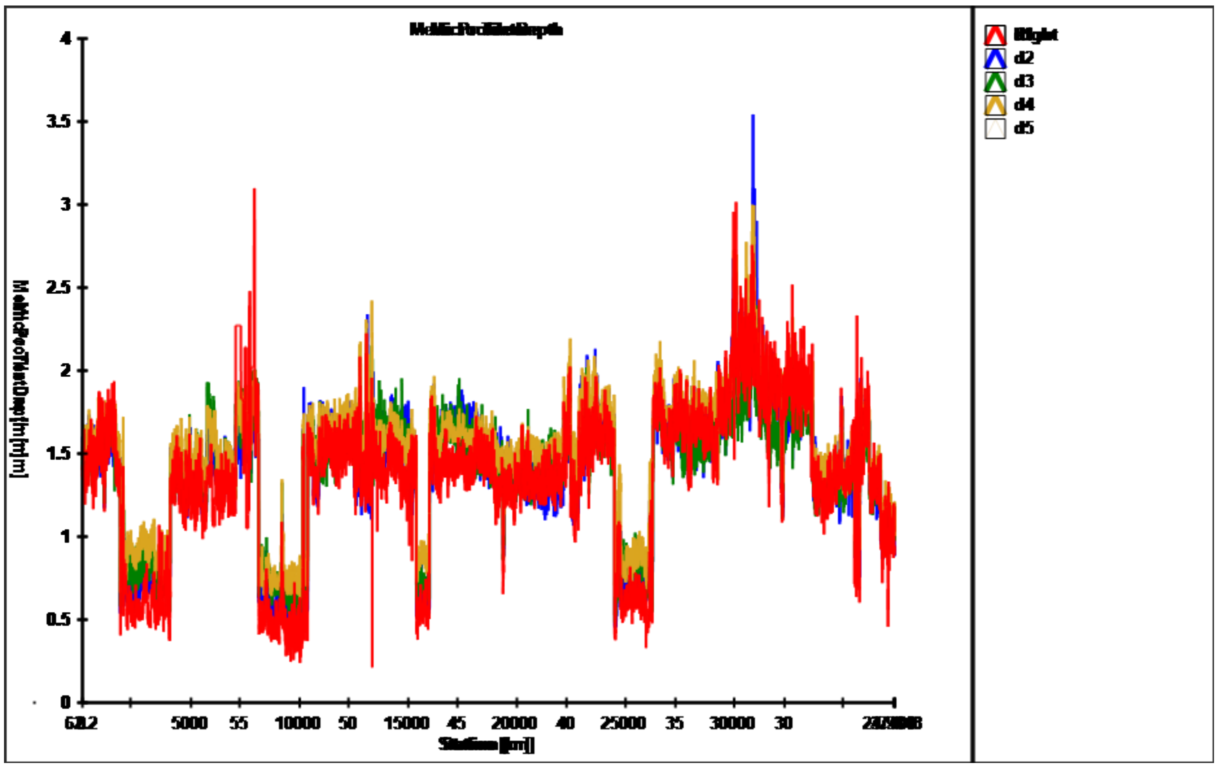
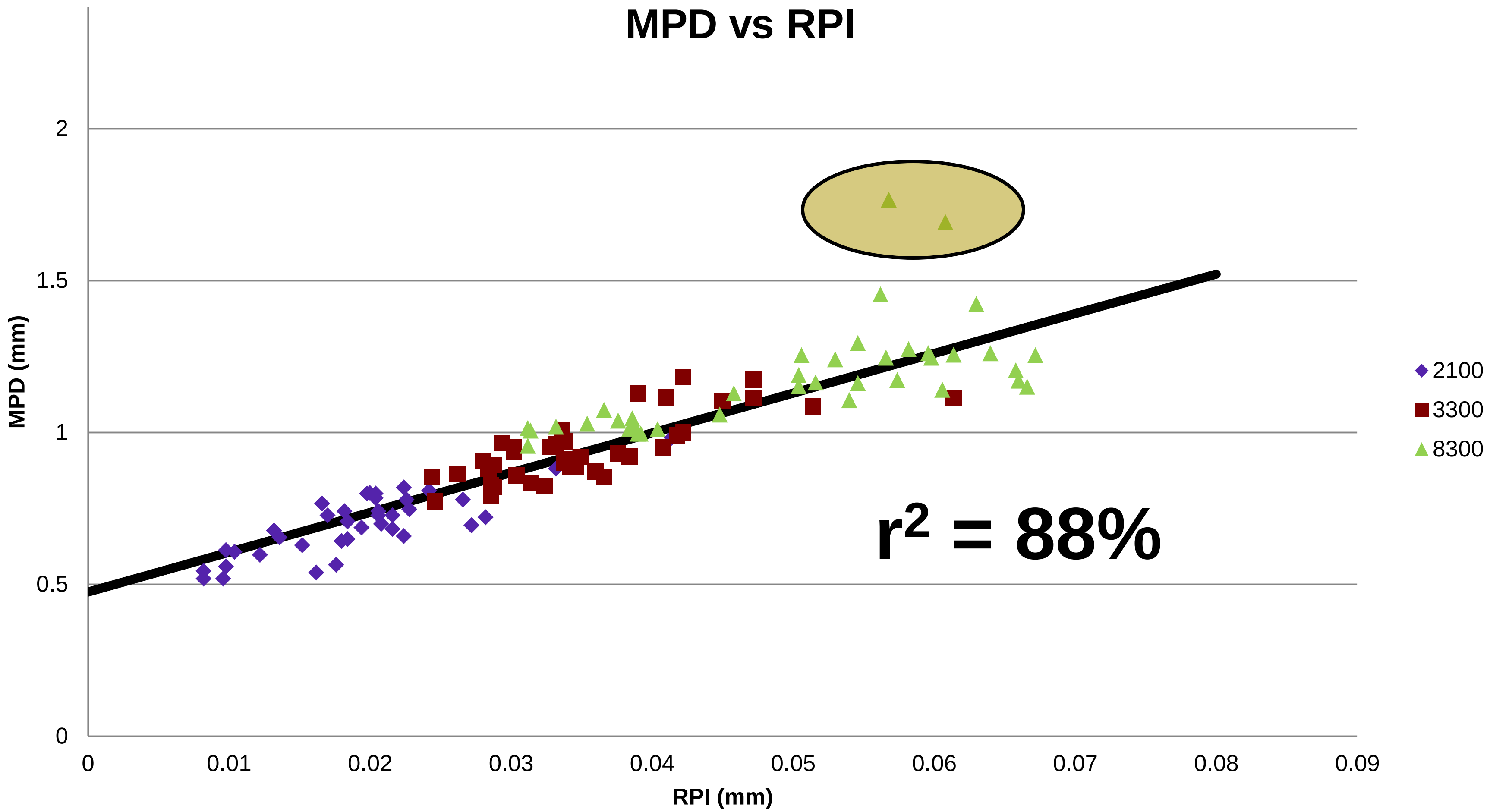
LCMS vs 64 KHz laser

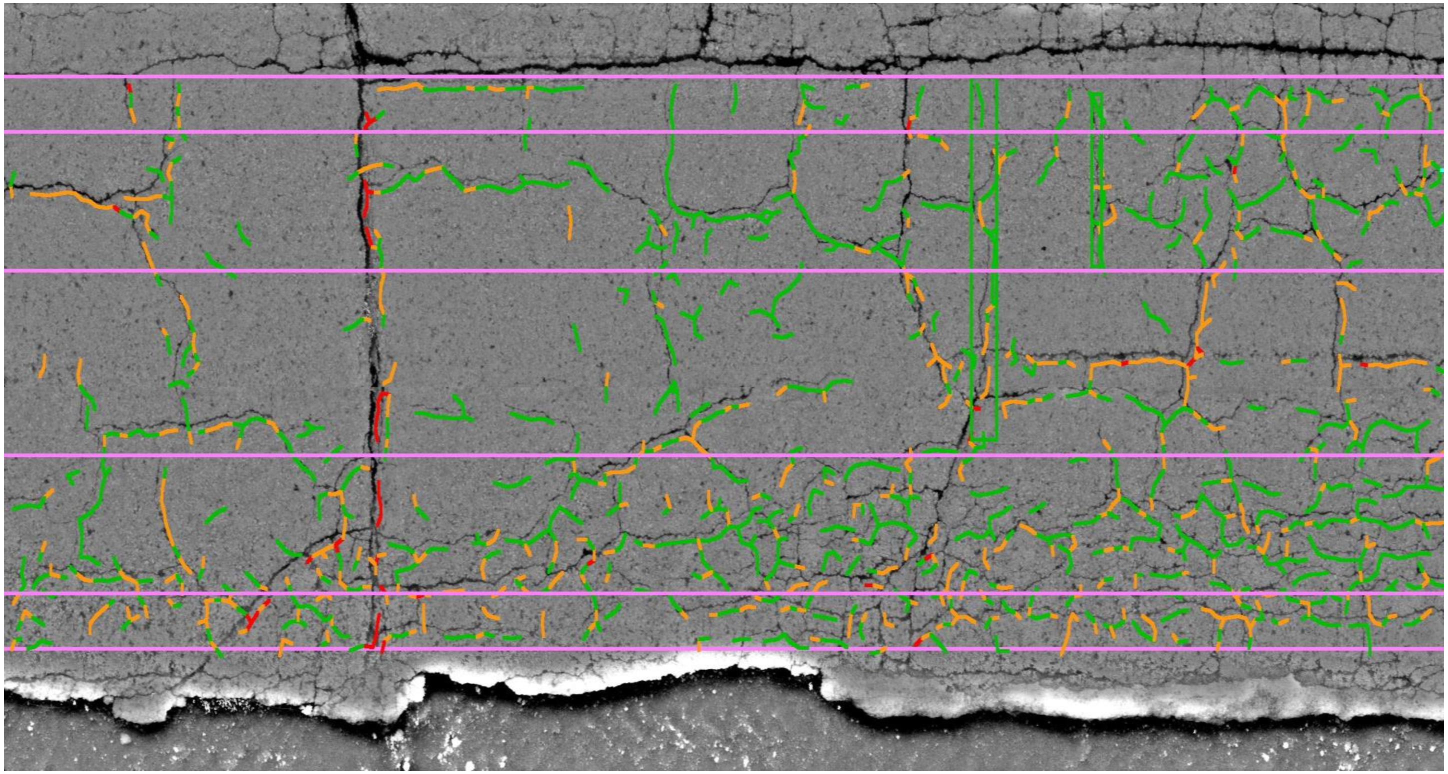


Macrotexture – Correlation between MPD and RPI



Macrotexture – Results for Section 08300

Pavemetrics



Right wheel path (10-20m)

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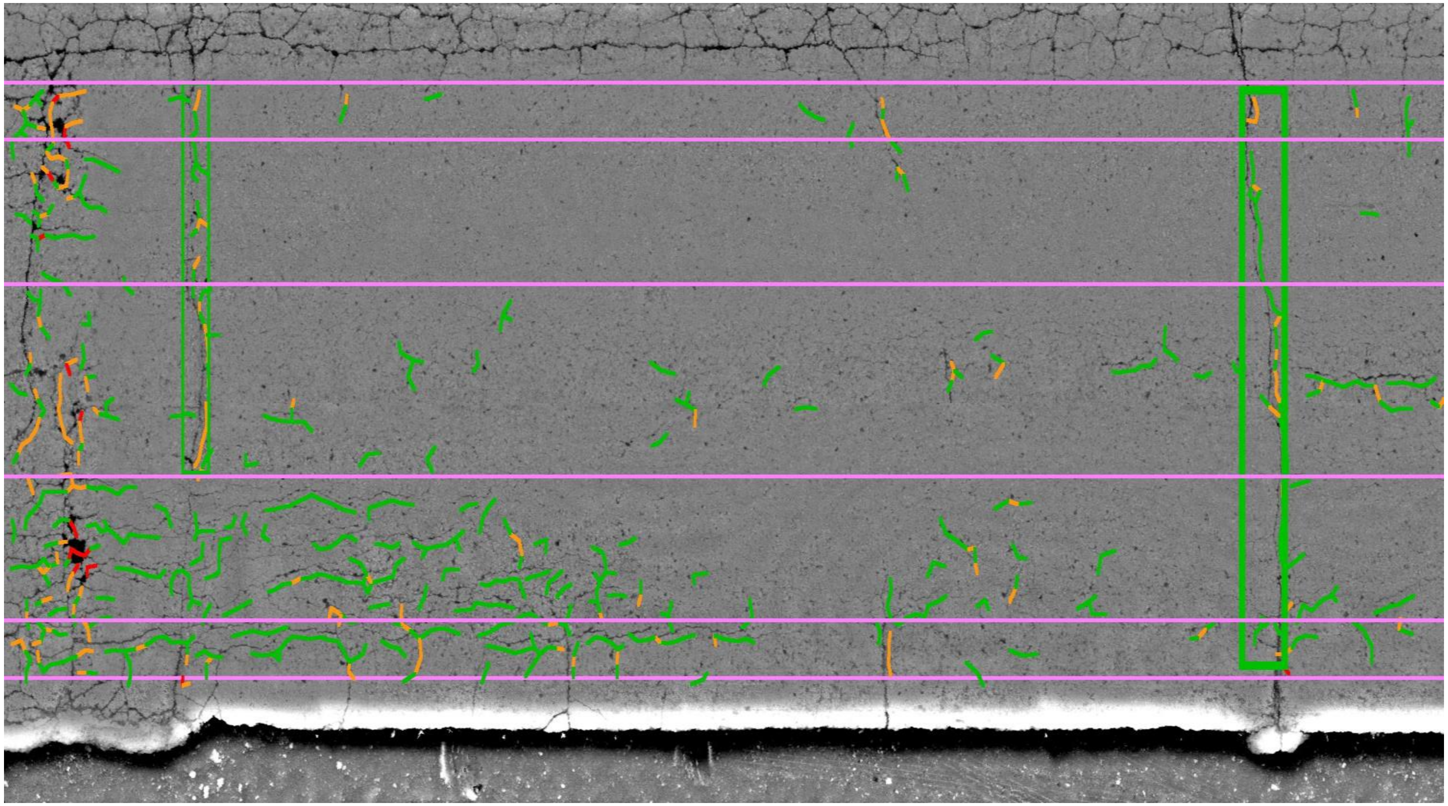
Macrotexture – Results for Section 08300

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

Pavemetrics

- **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

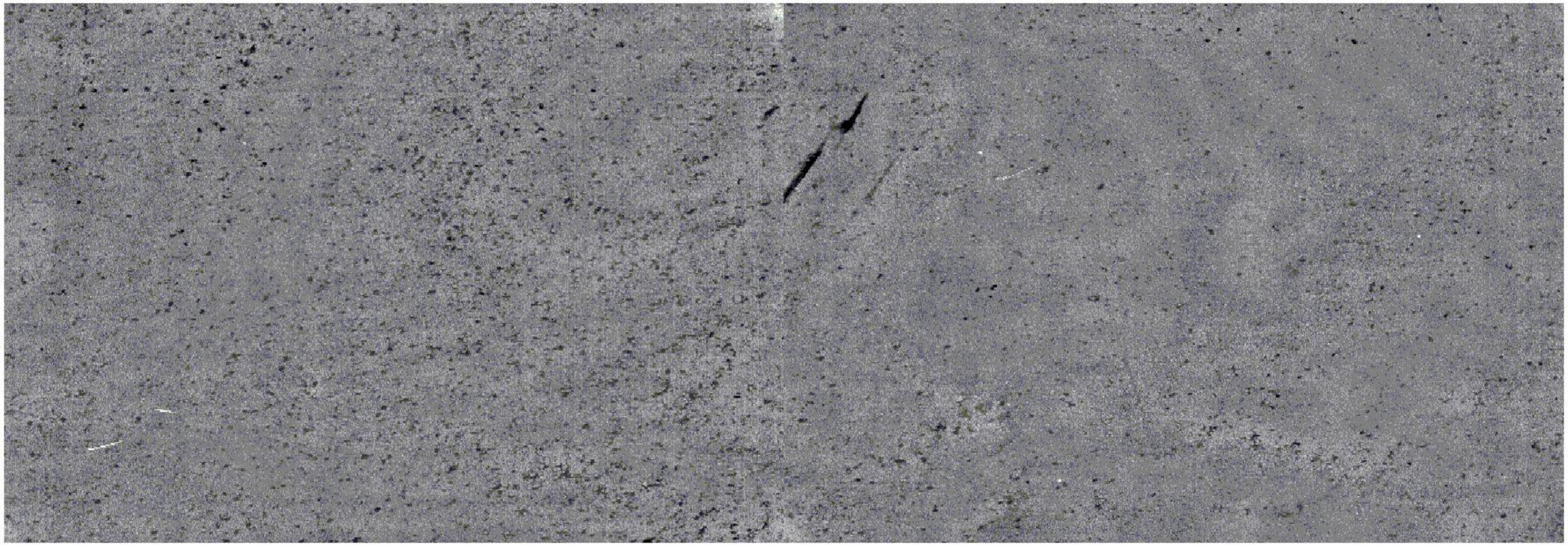
Rijkswaterstaat vehicle

Ravelling Index - RI

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

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

Aggregate loss detection



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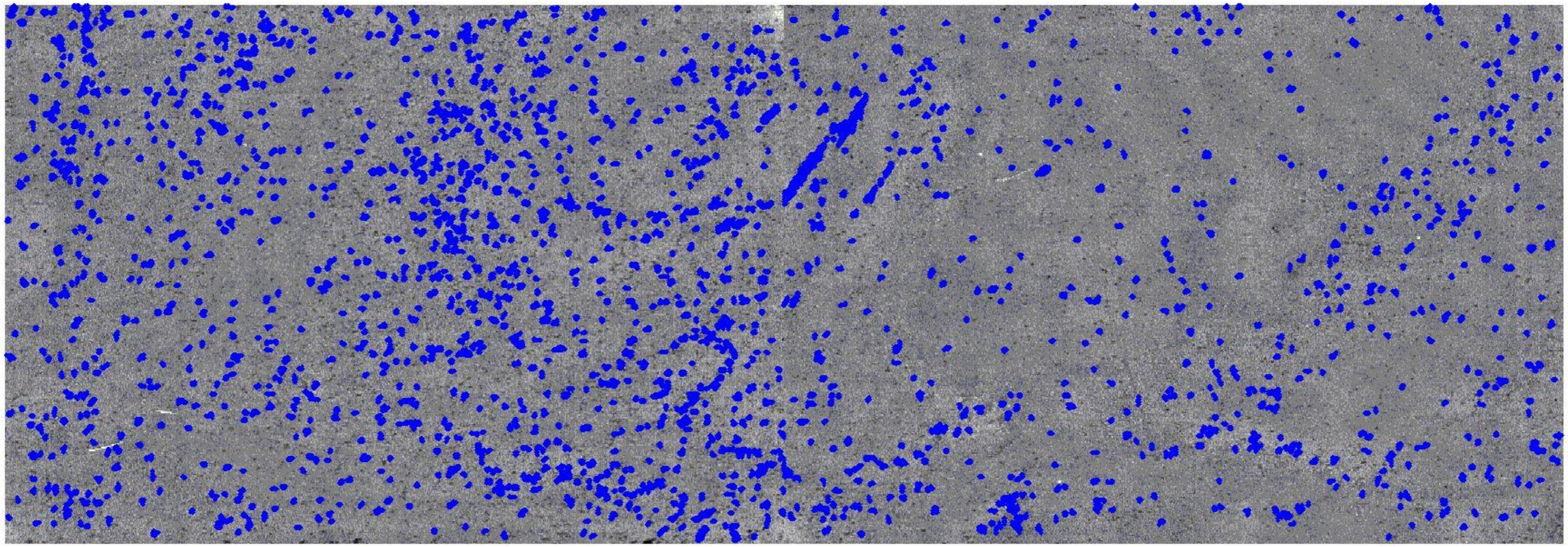
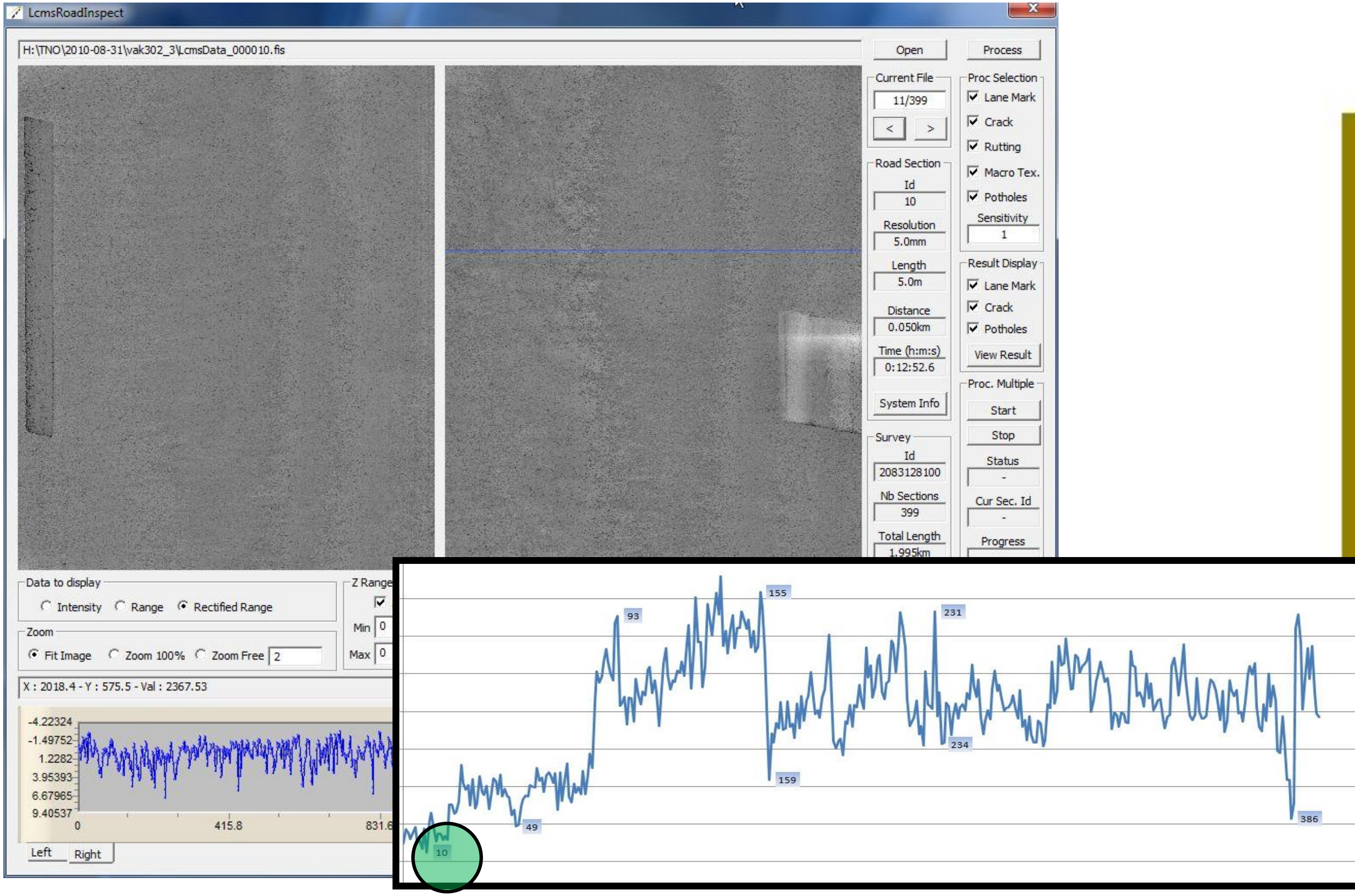
Aggregate loss detection



RI – Road test – Porous Asphalt in the Netherlands



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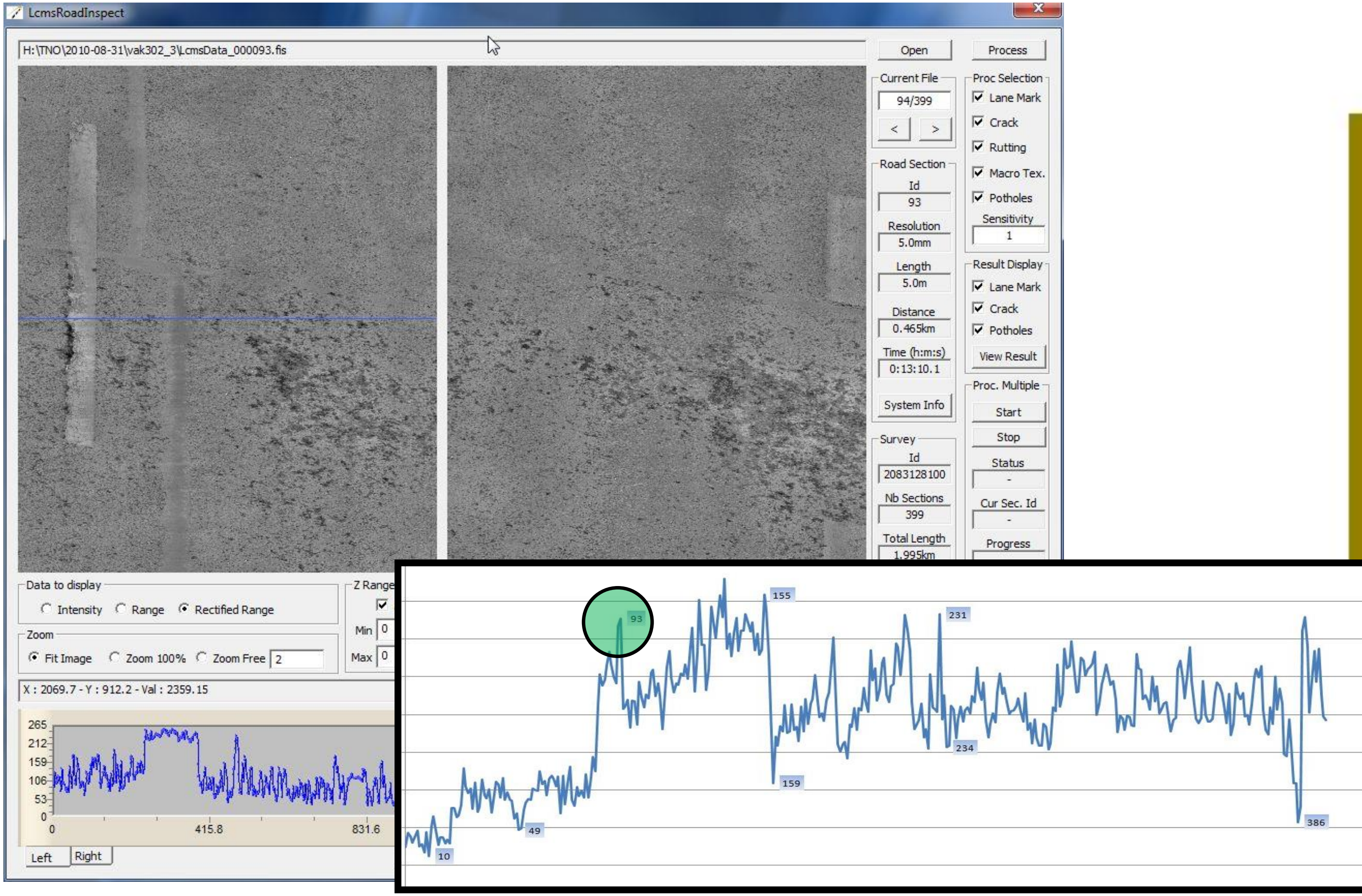
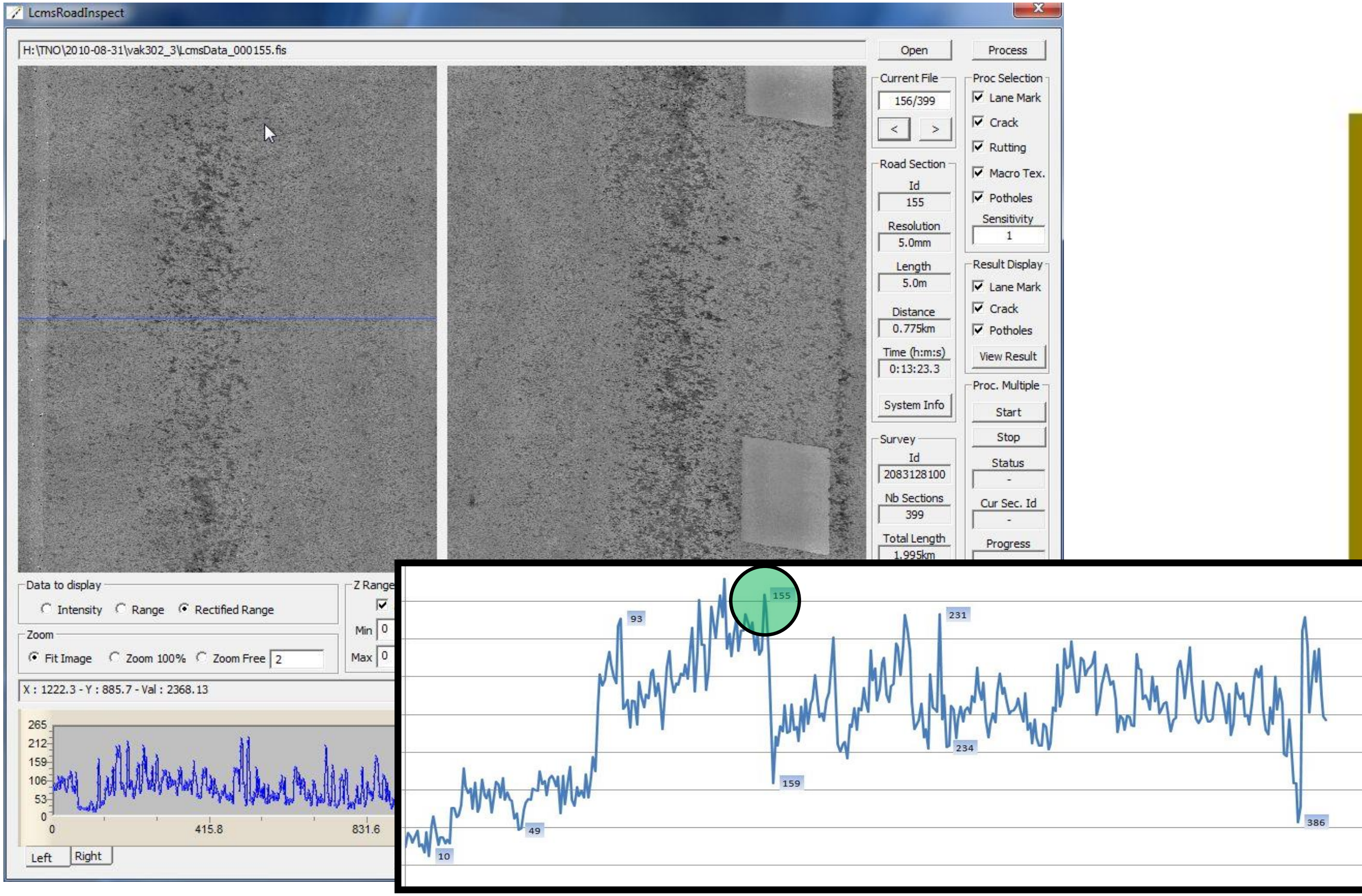
Road Section #93 : Transition between Ravelling and new pavement (Range)



Road Section #155 : Raveling patch



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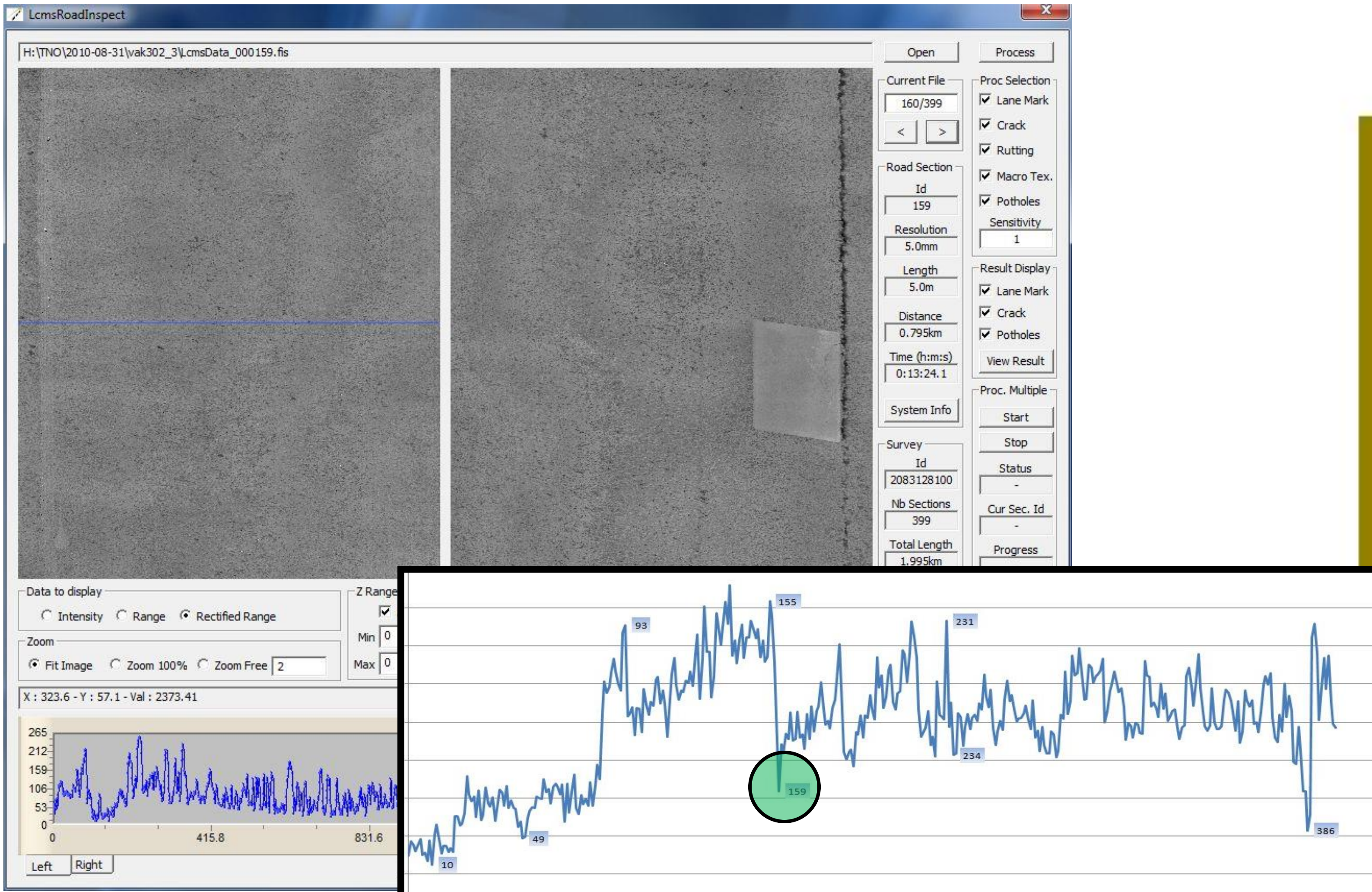
Road Section #159 : Smooth texture



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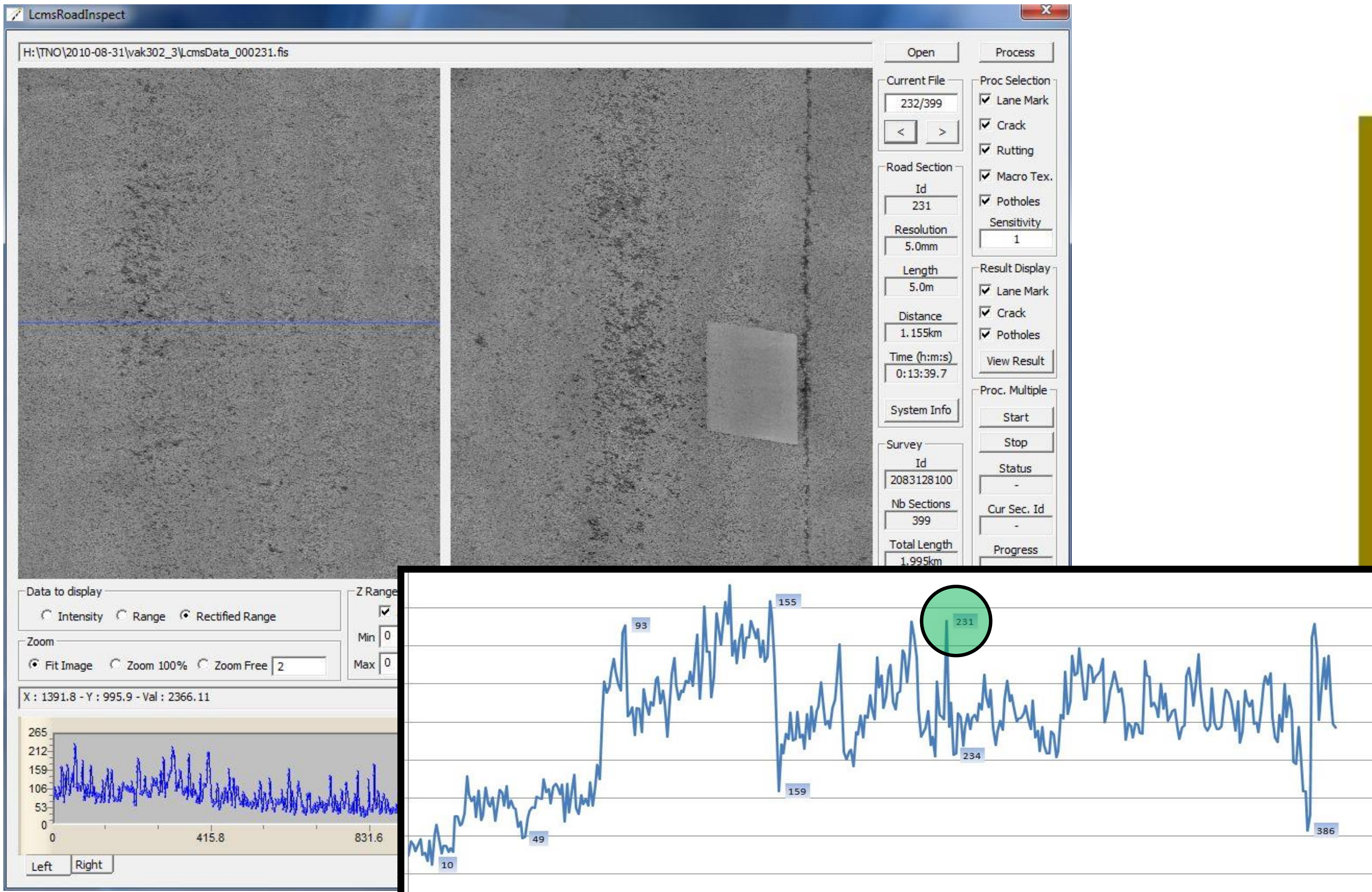
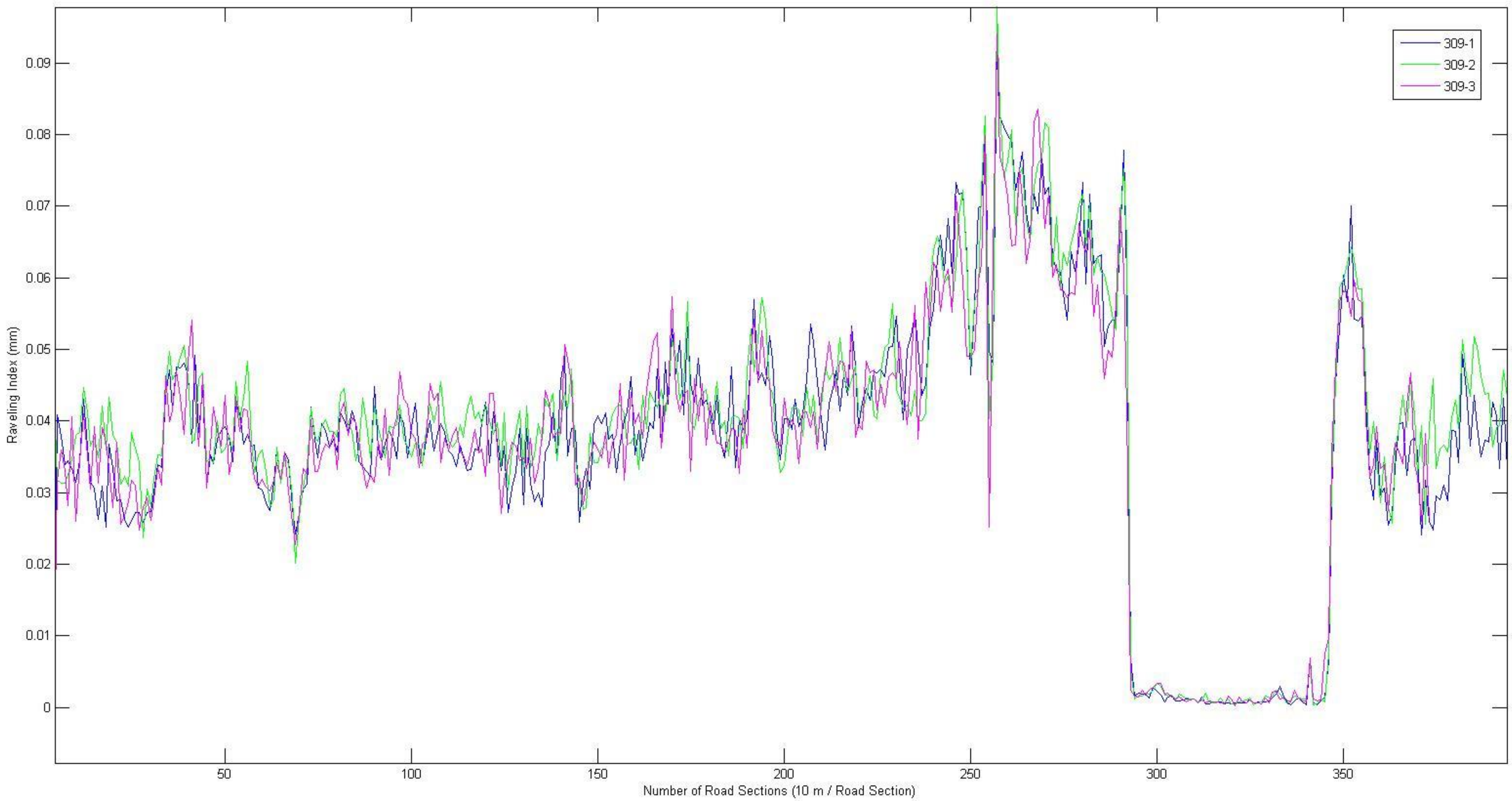
Road Section #231 : Raveling patch



Ravelling Index - Repeatability (Porous asphalt Netherlands)



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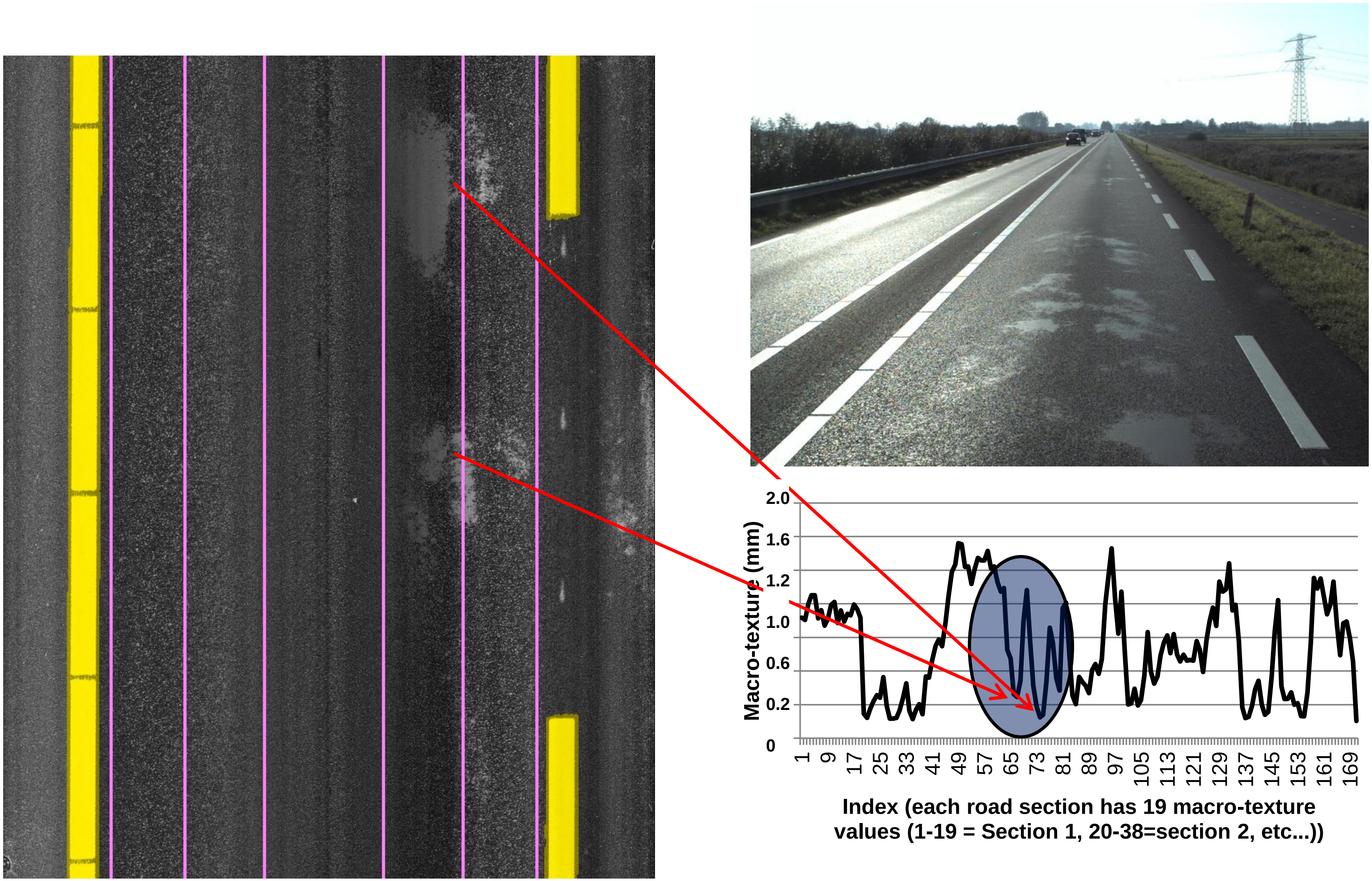
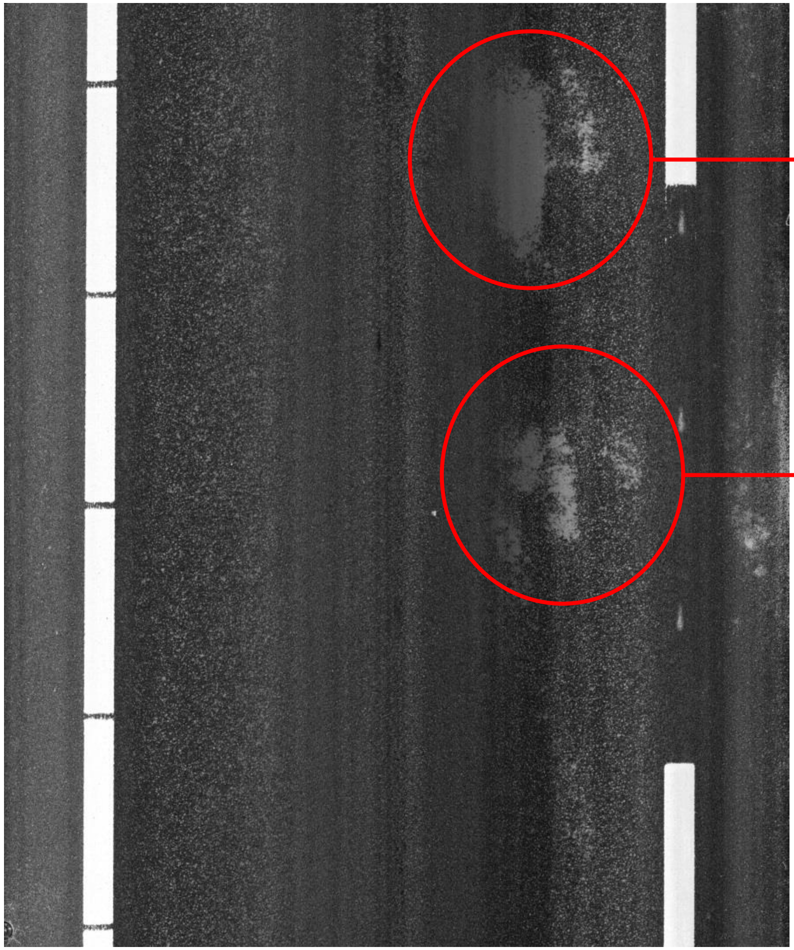
Bleeding

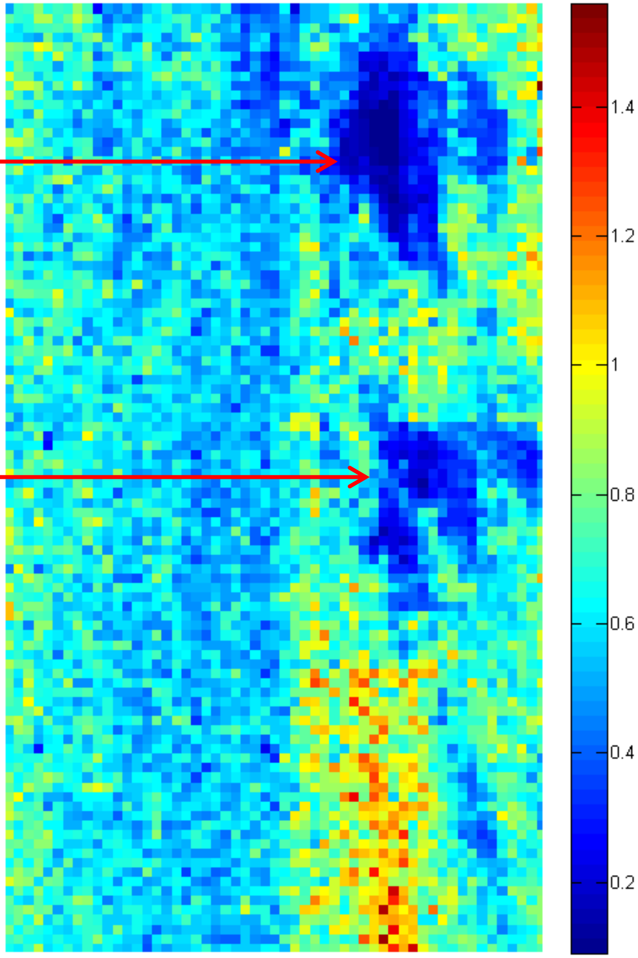


Macrotexture: bleeding

Intensity image



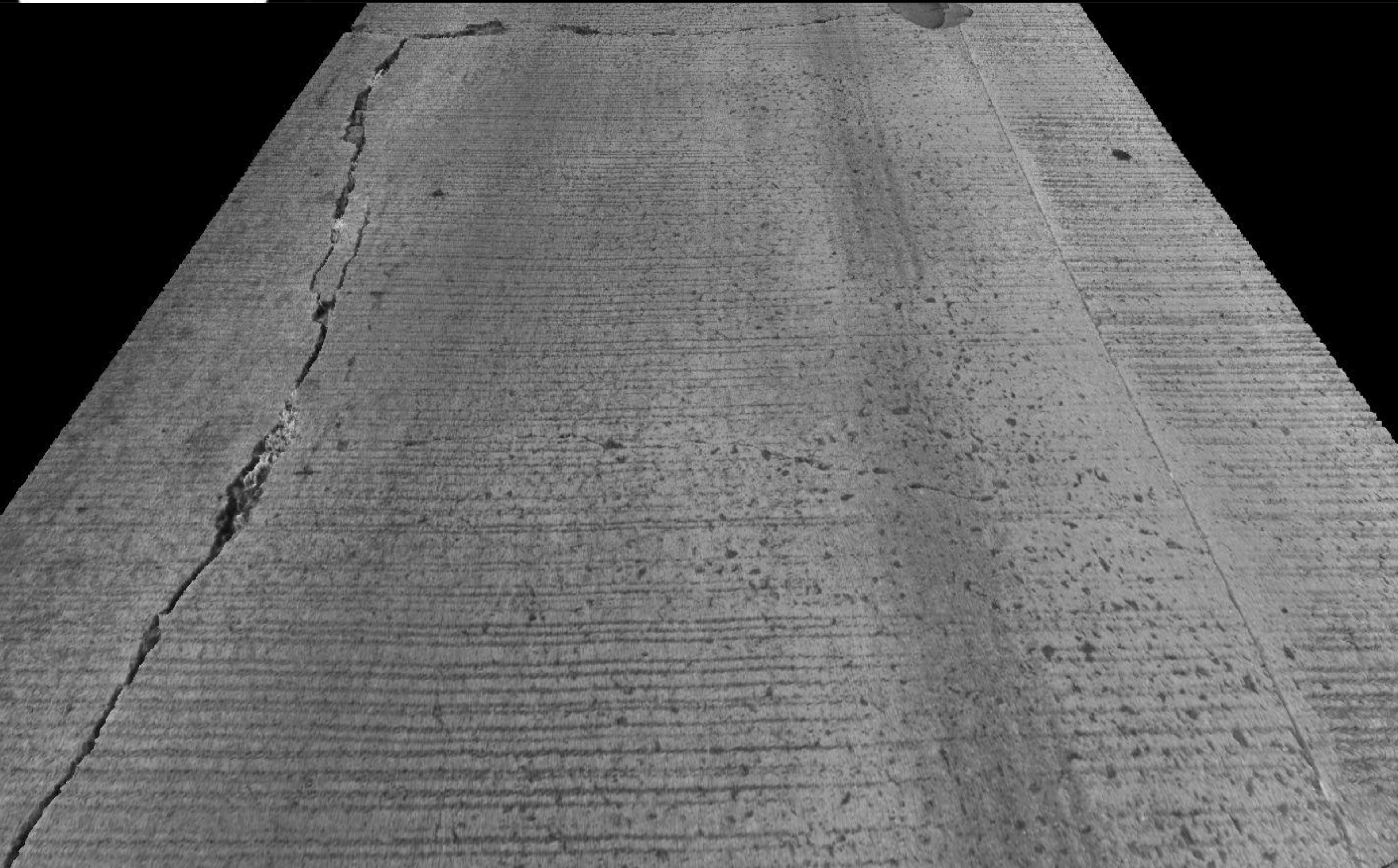
Texture image (MTD, mm)



Pavemetrics

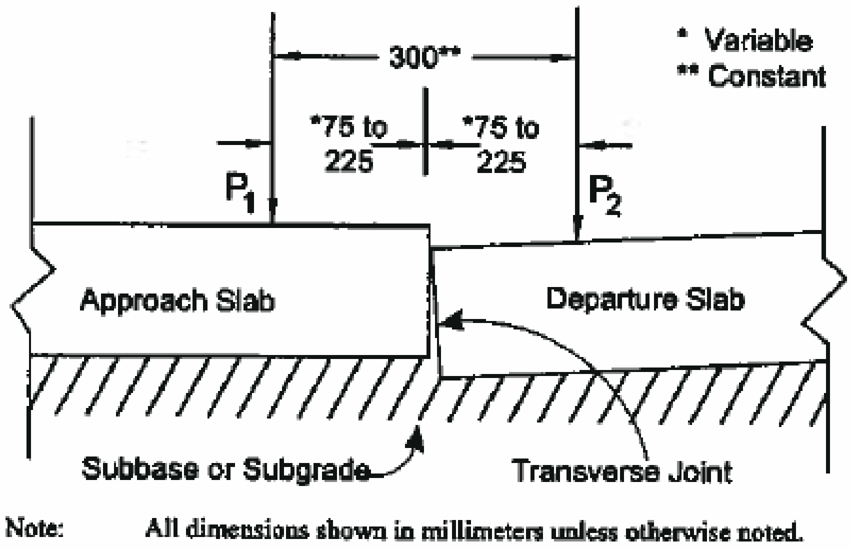
Concrete roads

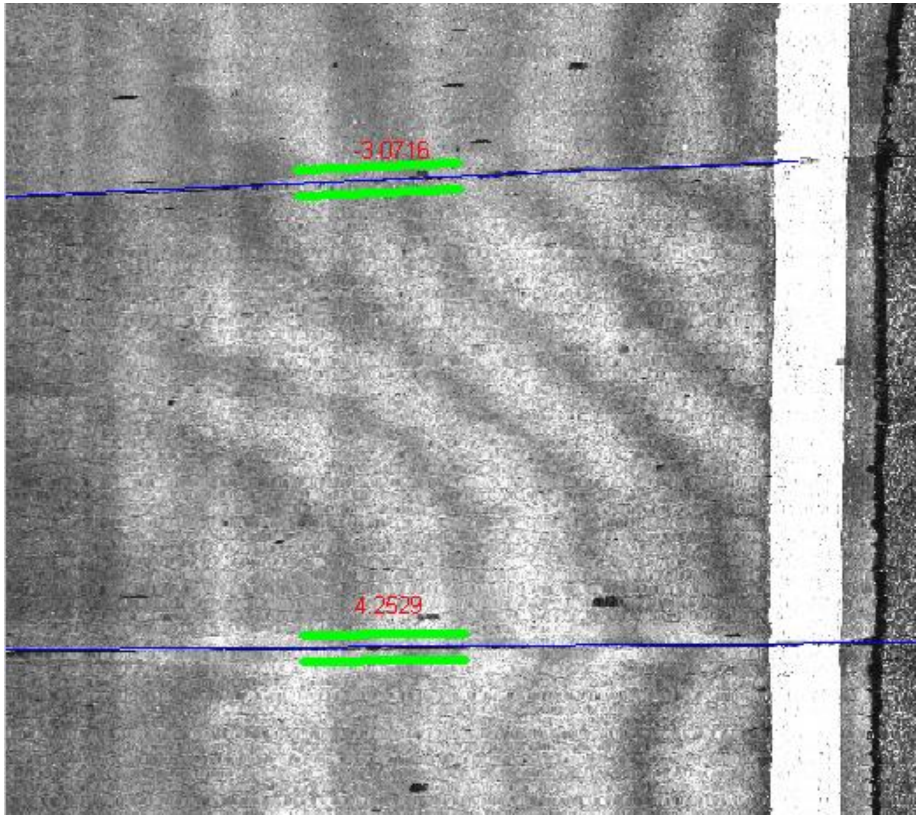
Concrete Roads



Concrete Roads

Joint detection and faulting

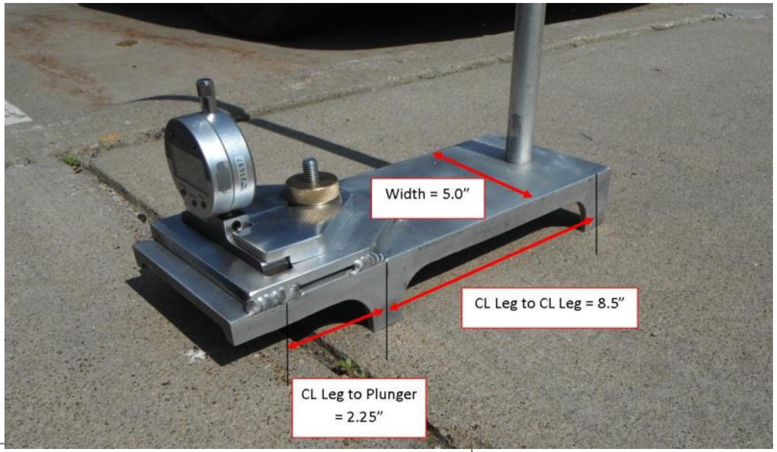


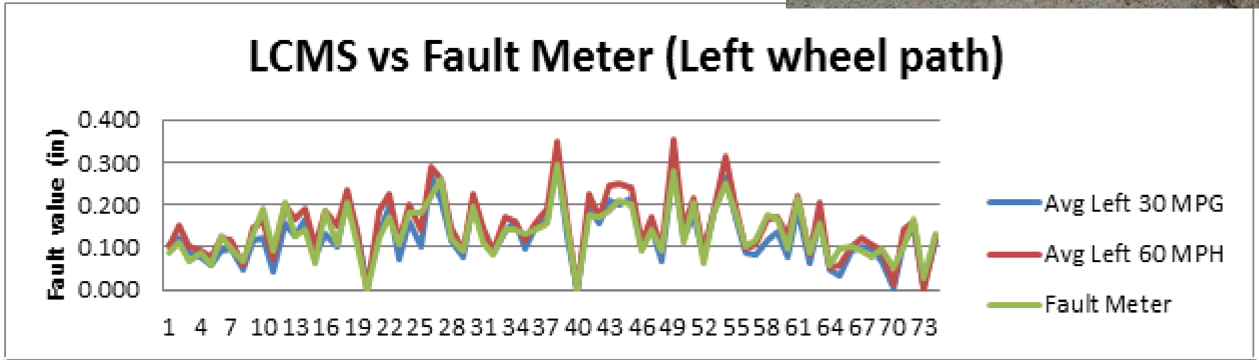


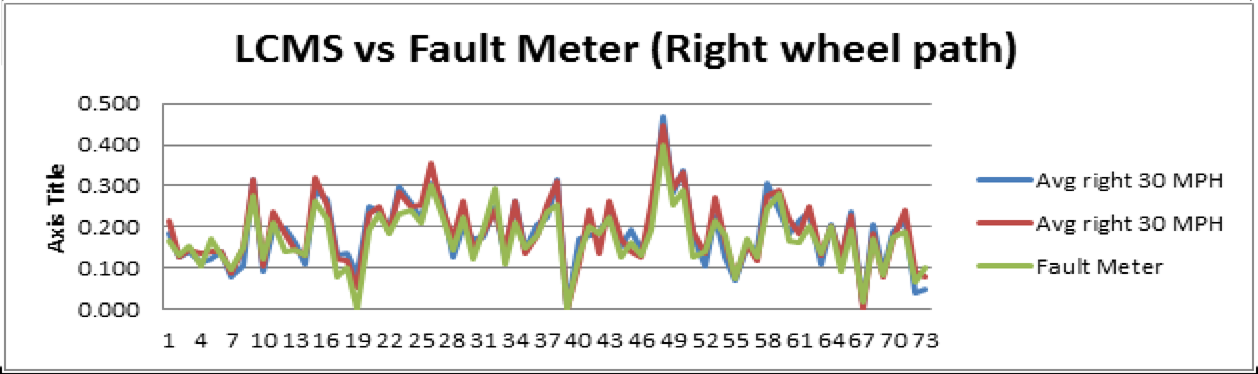
Pavemetrics

Faulting tests (South Dakota DOT)

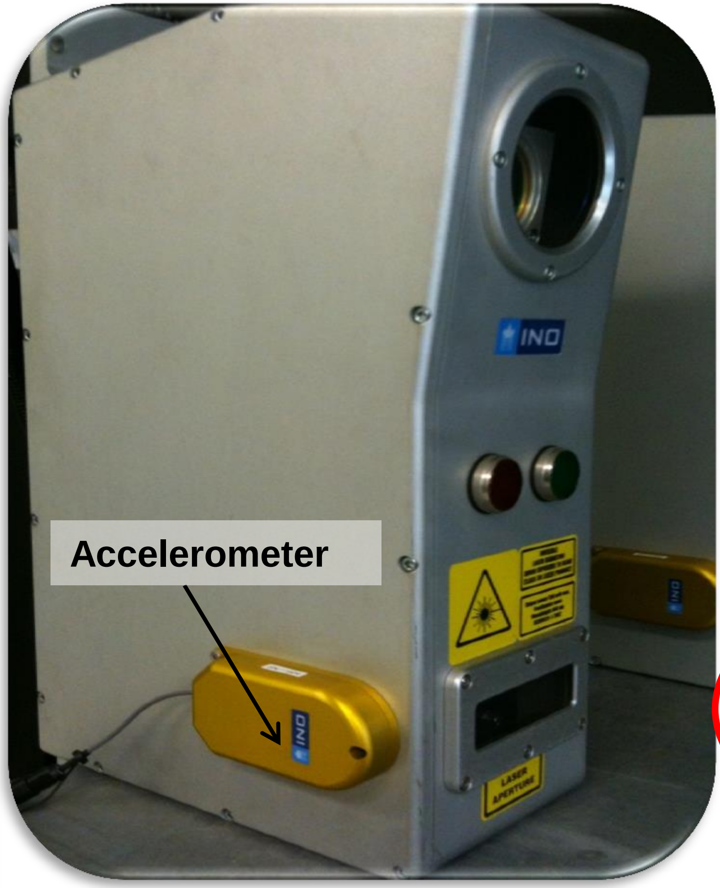
SD DOT faulting	30 and 60mph
Repeatability (LCMS)	0.98 (Correlation)
Average Bias (vs Faultmeter)	<0.5mm
LCMS vs Faultmeter	>0.92 (Correlation)

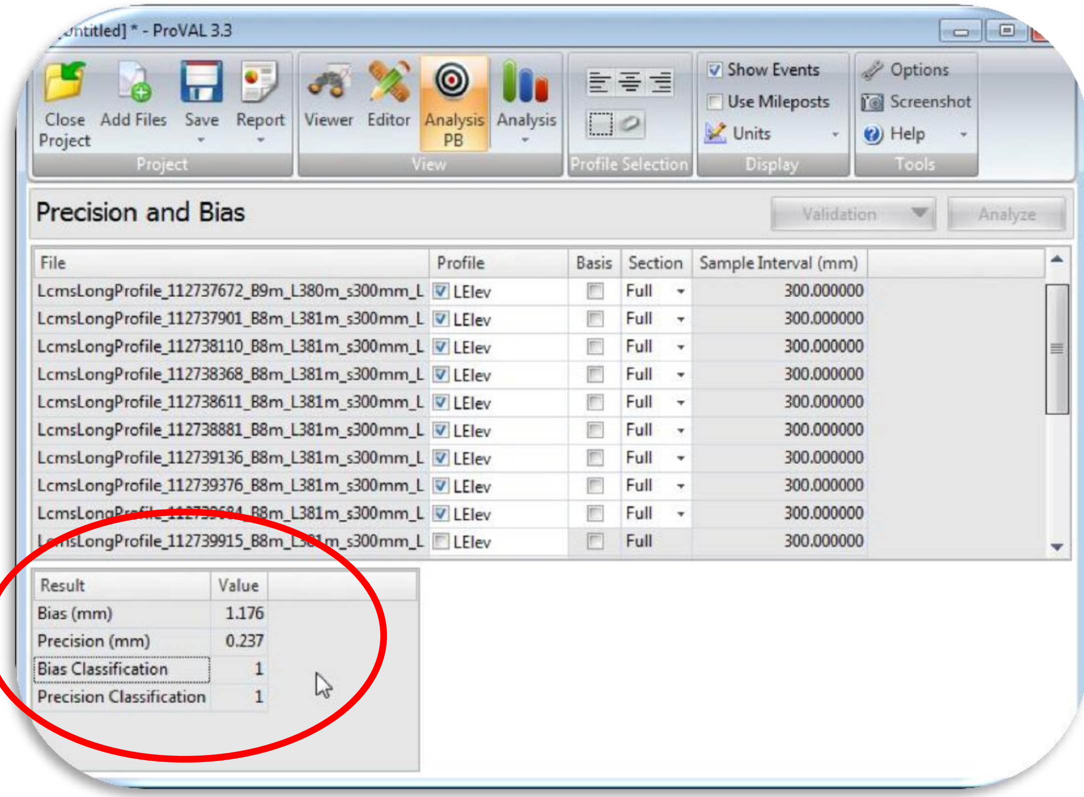


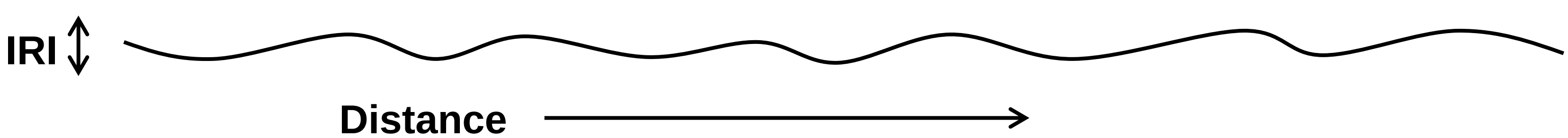




ASTM E950 Class 1 Device for Longitudinal Profiling

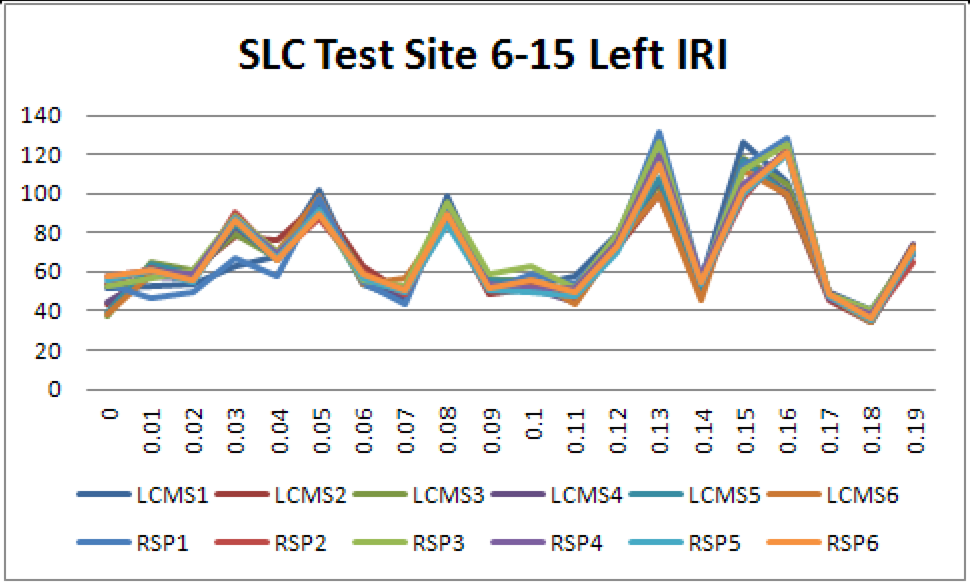


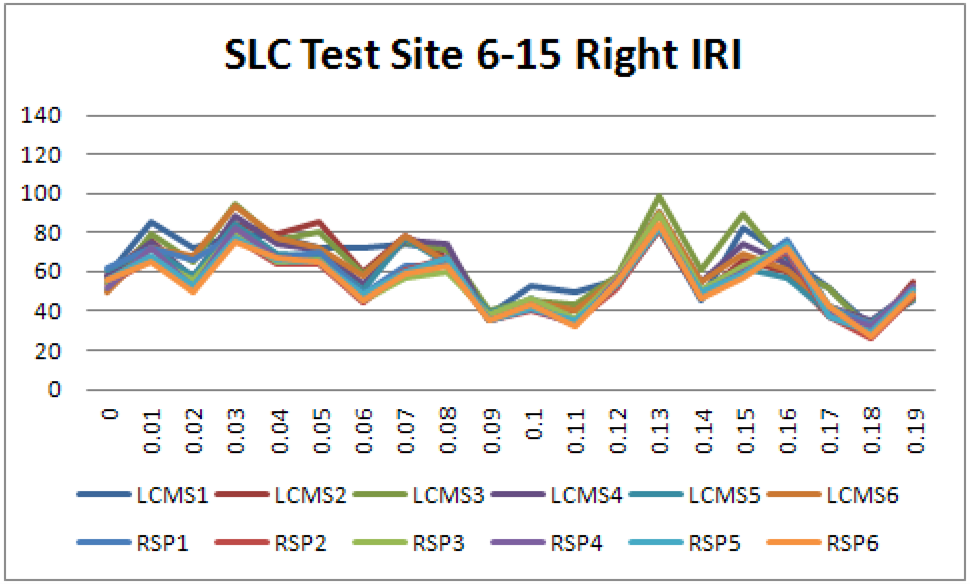




Pavemetrics

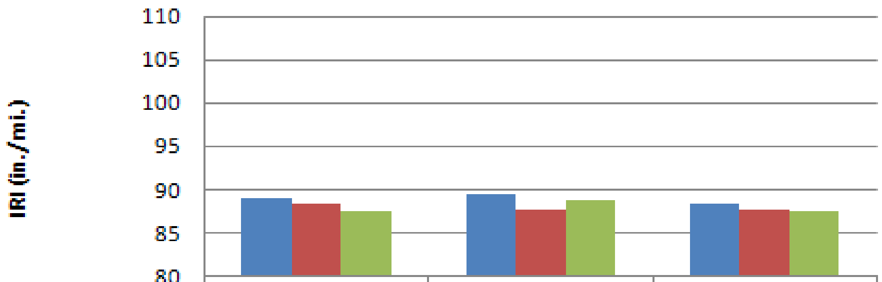
UTAH DOT – Test sites





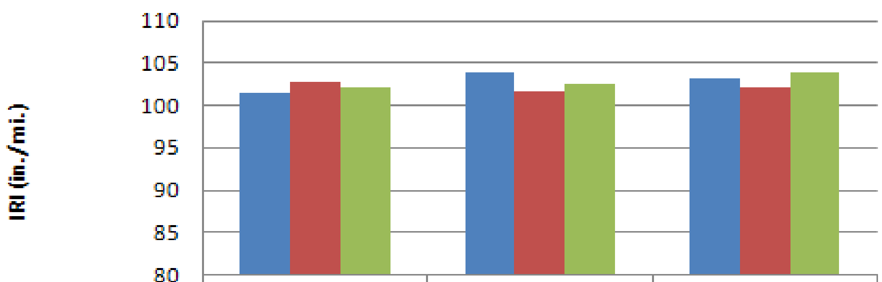
MassDOT

MassDOT IRI Repeatability Runs (Left)



	Run 1	Run 2	Run 3
MassDOT ARAN	89.1	89.4	88.3
RSP	88.3	87.7	87.7
LCMS	87.4	88.7	87.4

MassDOT IRI Repeatability Runs (Right)



	Run 1	Run 2	Run 3
MassDOT ARAN	101.4	103.8	103.1
RSP	102.7	101.6	102.2
LCMS	102	102.6	103.9

Pavemetrics

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

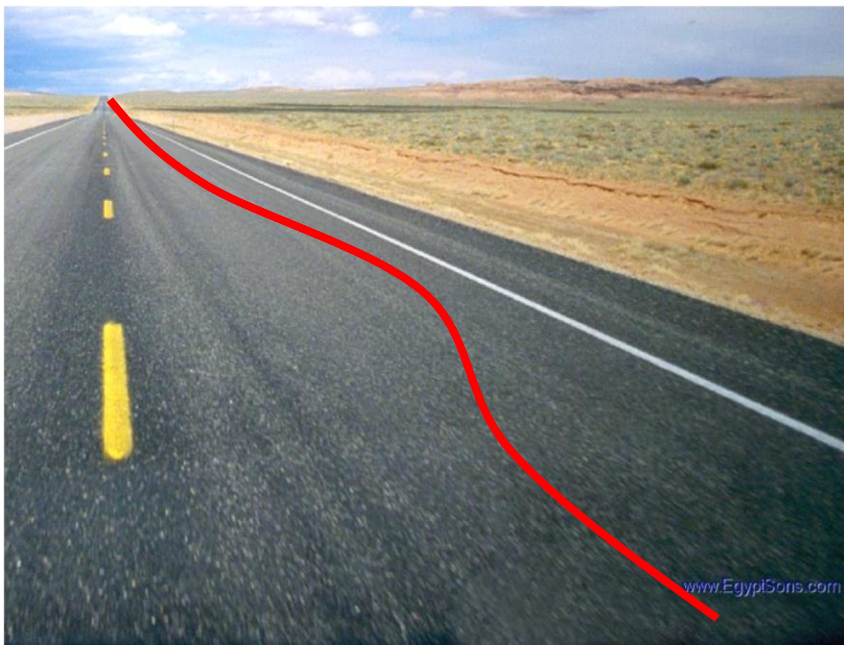
- IRI values are stable and close to the values obtained with the reference instrument (Surpro).

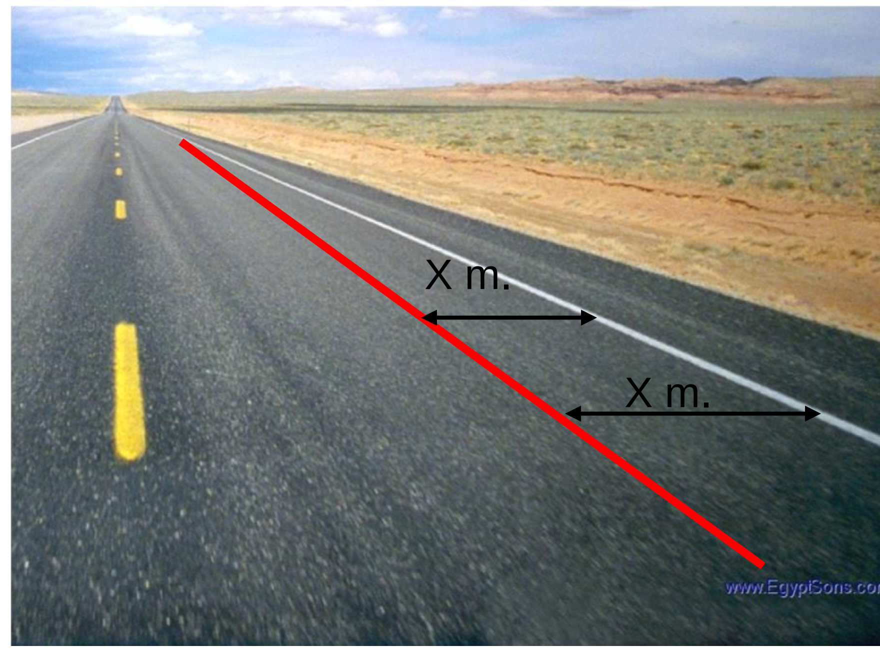
Pavemetrics

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

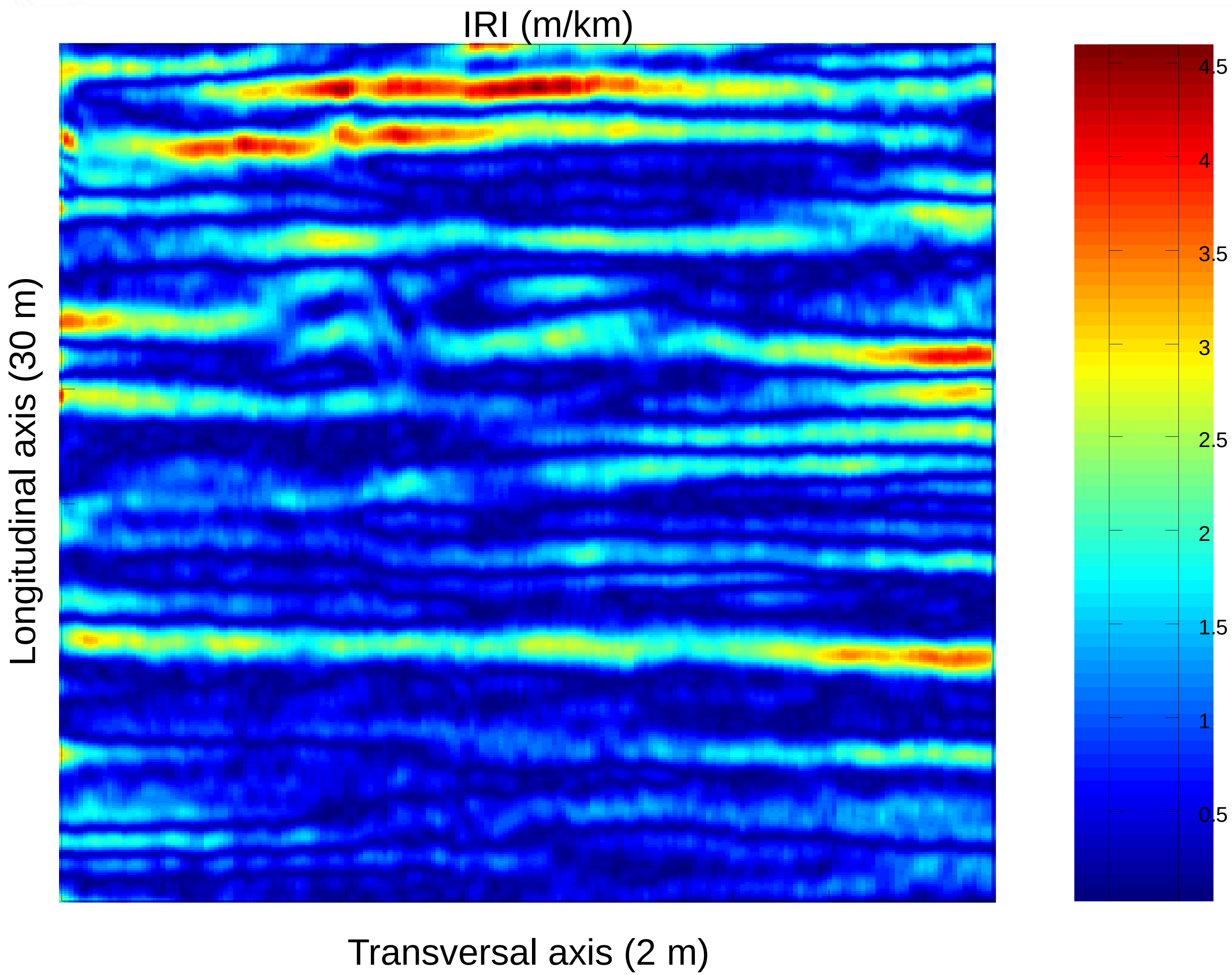
Pavemetrics

Results: lane tracking

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

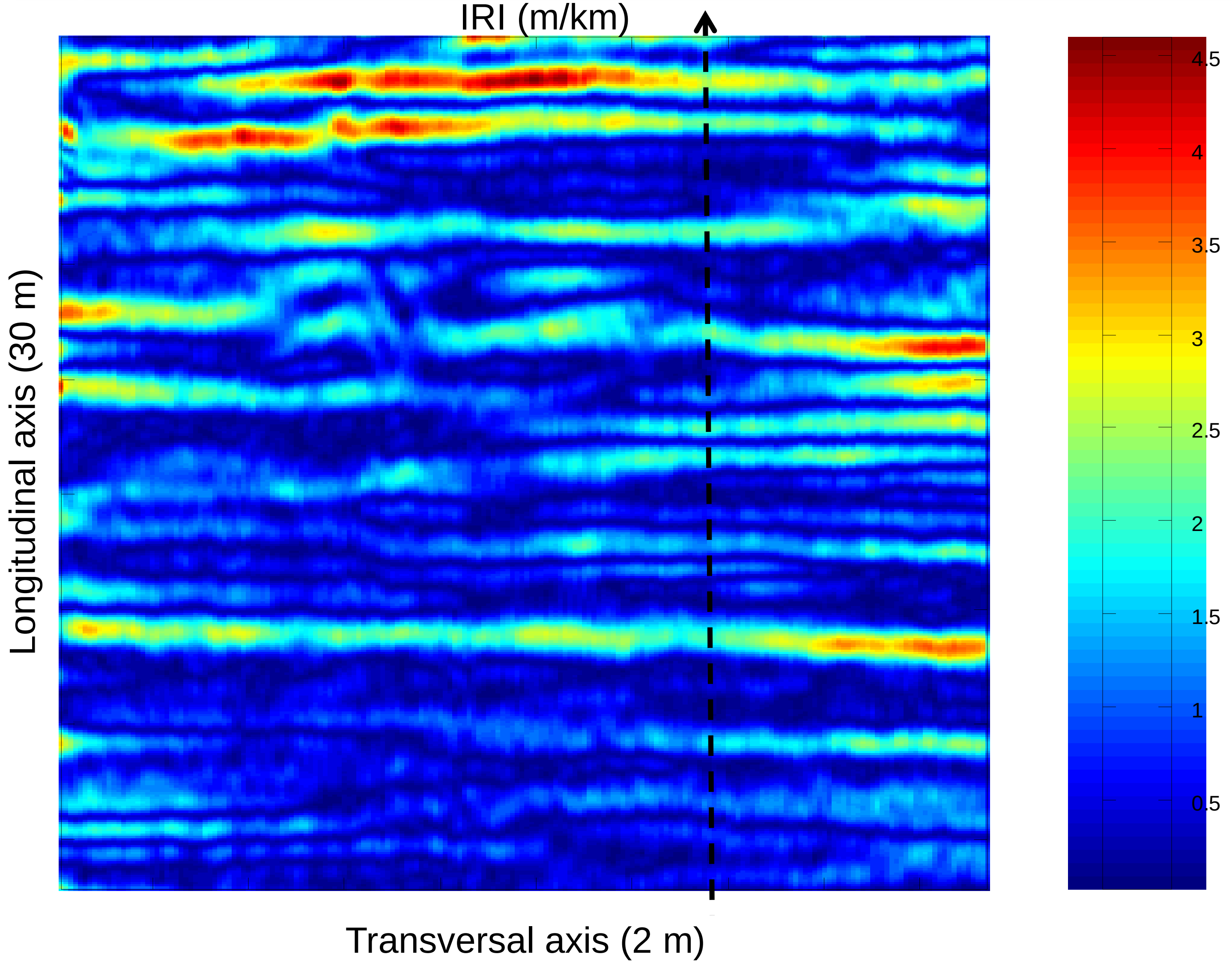
	With lane tracking		No lane tracking	
Run	IRI Left (m/km)	IRI Right (m/km)	IRI Left (m/km)	IRI Right (m/km)
1	1.33	1.50	1.16	1.43
Reference value	1.29	1.47	1.29	1.47
Difference	3.1%	2.0%	10.1%	2.7%

Results: IRI image (2 x 30m)



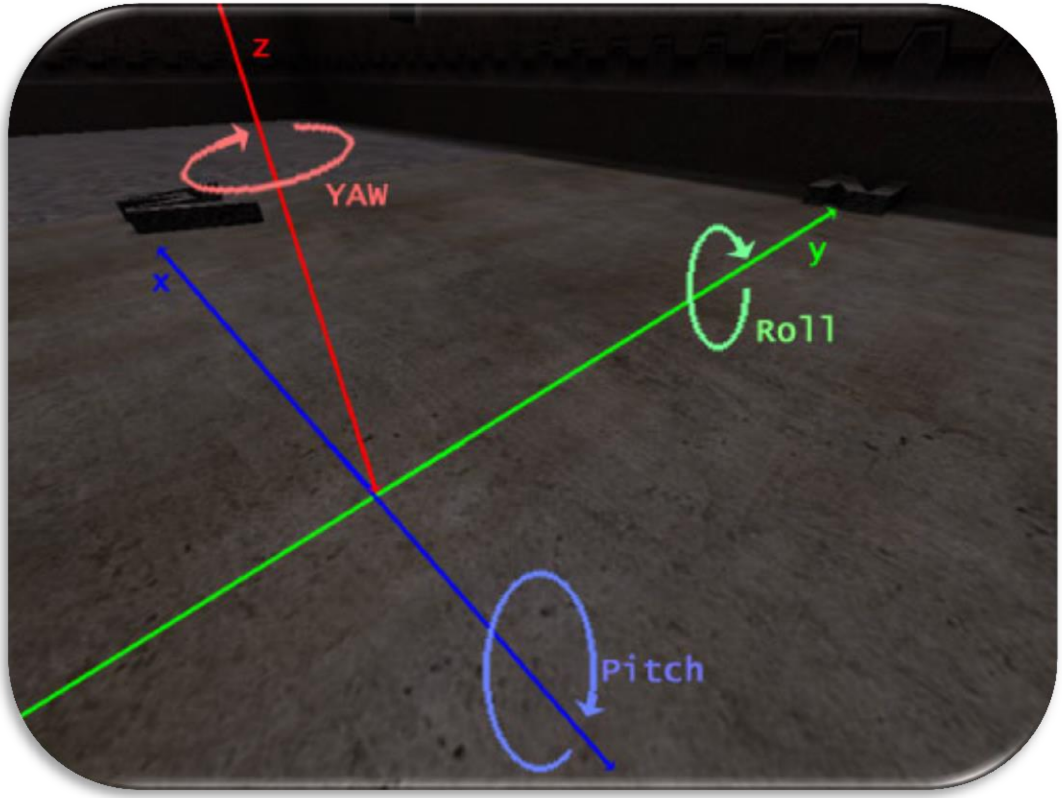
Results: IRI image (2 x 30m)

Pavemetrics



Road Geometry

IMUs

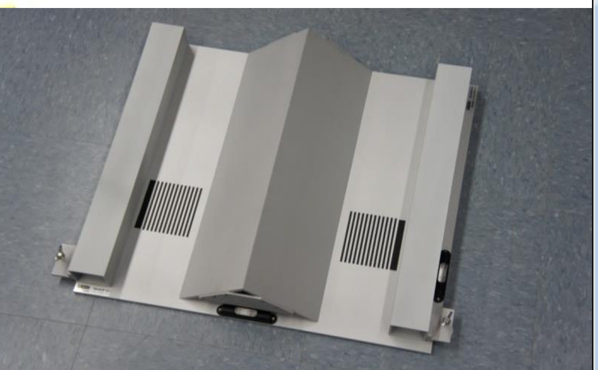


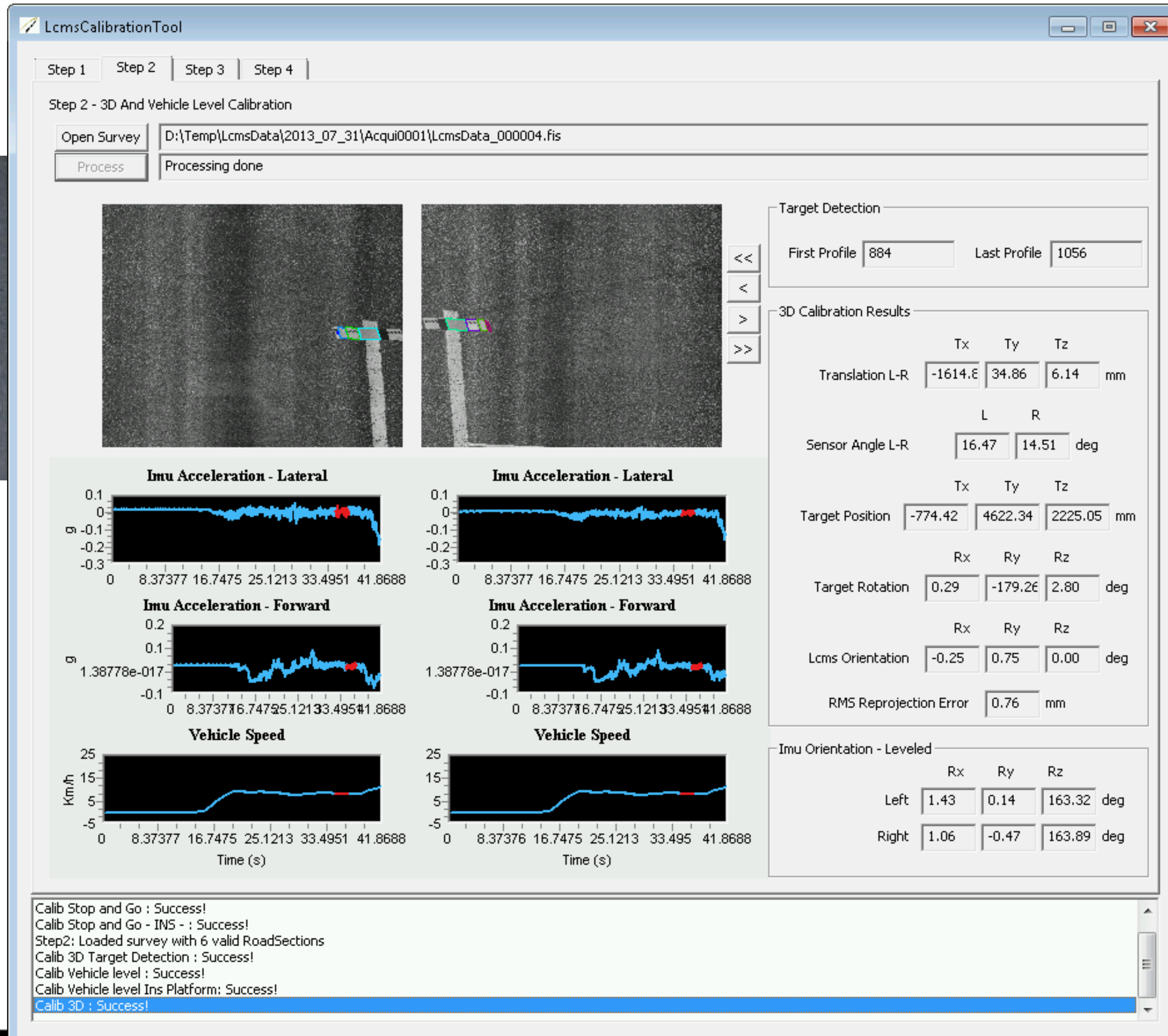
LCMS sensor/IMU coordinates transformation

IMU

Pavemetrics

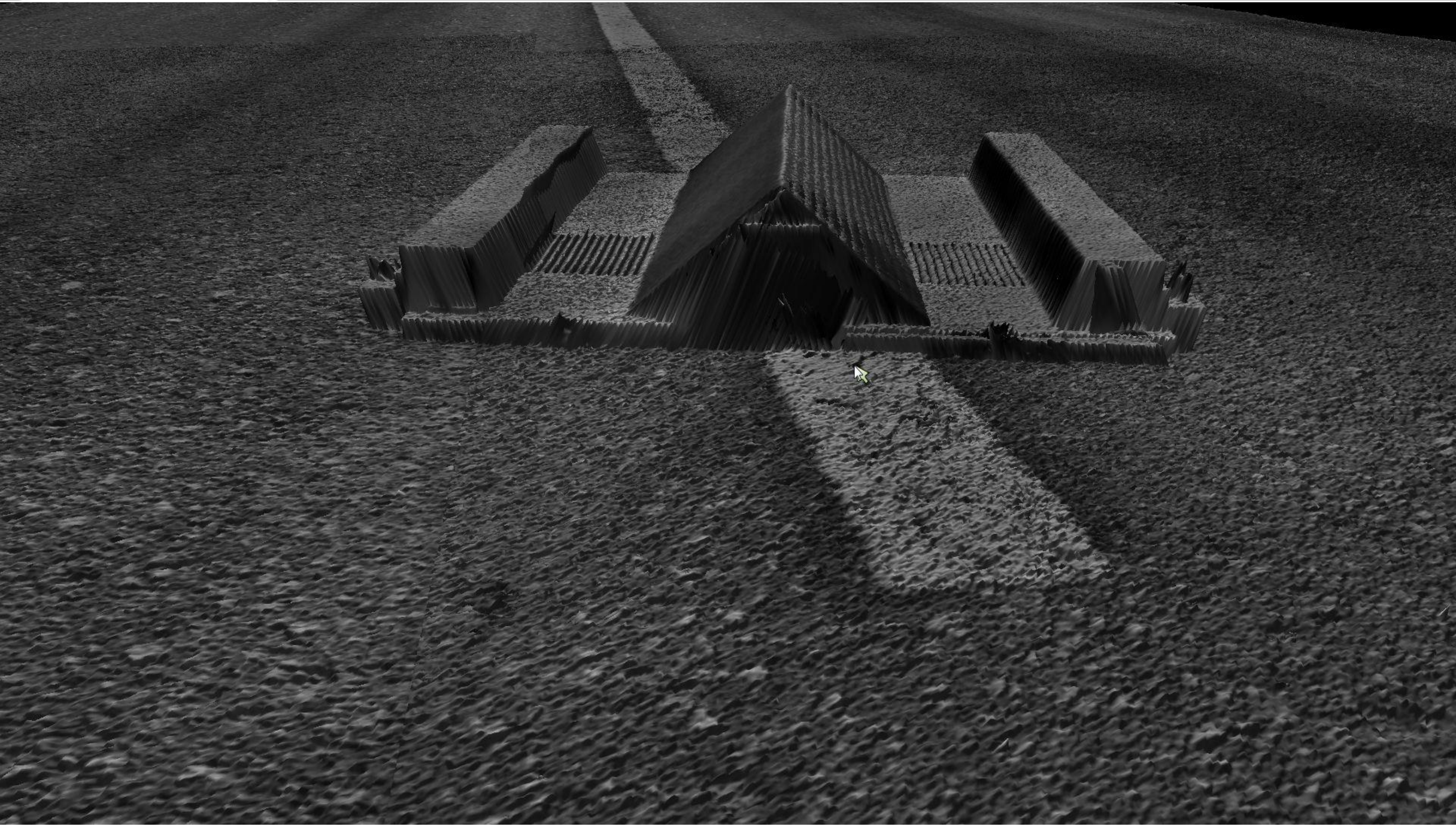
Sensor to sensor and world (gravity) position calibration





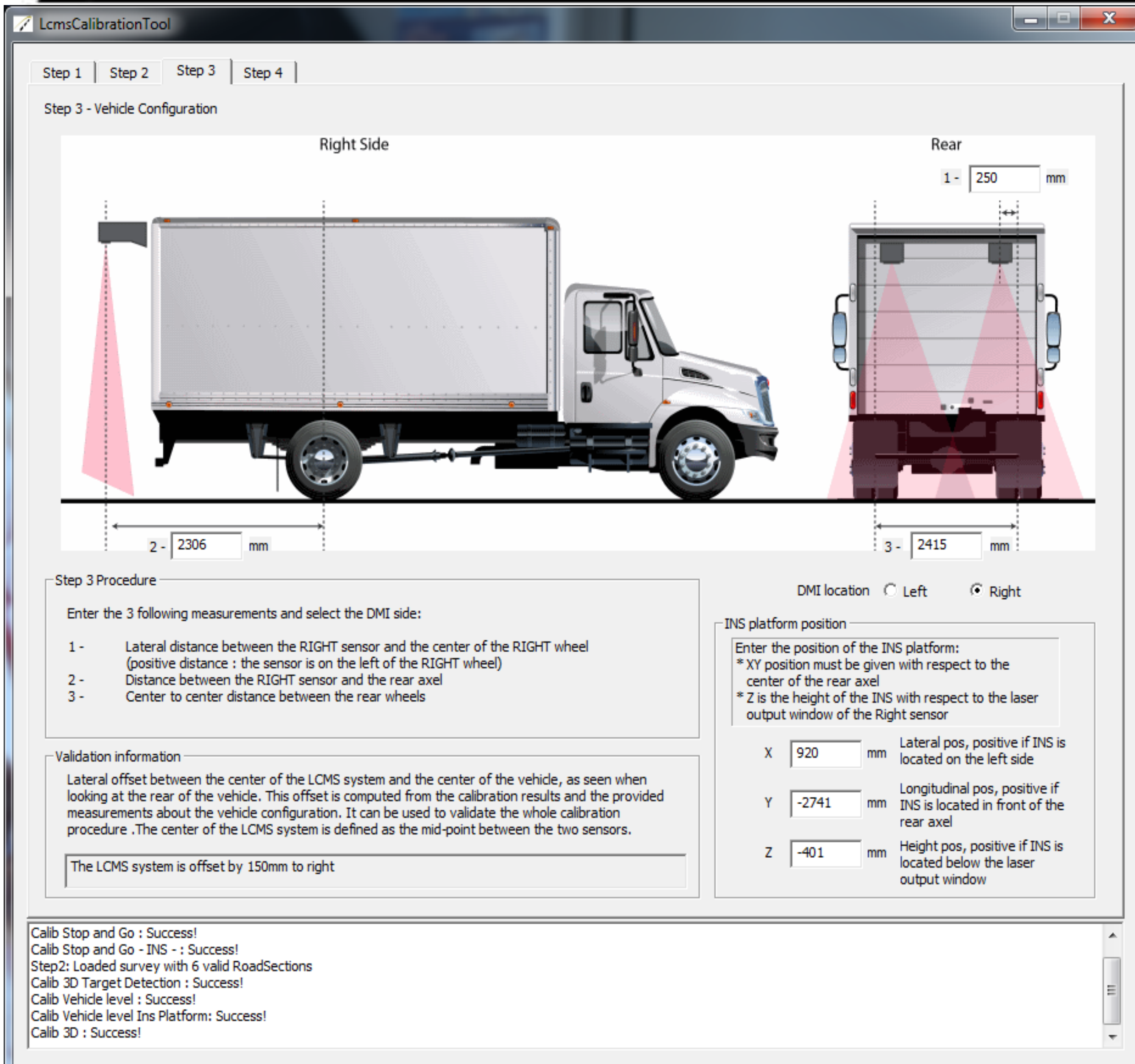
Sensor to sensor and world (gravity) position calibration

Sensor to sensor and world (gravity) position calibration



Pavemetrics

Wheel/encoder vs IMU coordinates transformation



Field Validation Tests – Slope and Crossfall

Pavemetrics

Slope/Xslope field validation

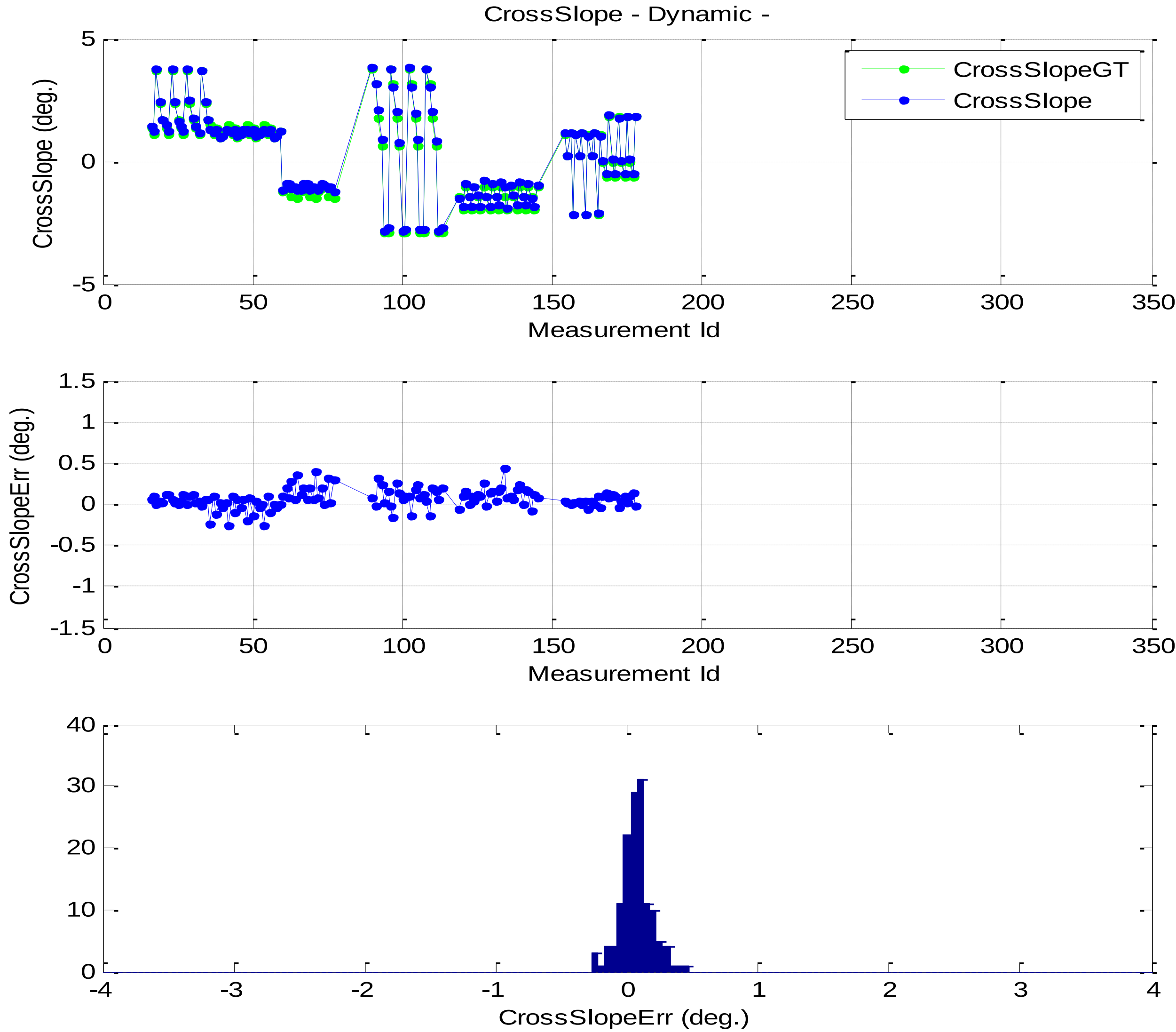
- Slope/Xslope was measured 50 different locations with digital inclinometer (0.1 degree accuracy)
- Xs were marked on road to identify measurement locations.
- Xs were identified in LCMS data and Slope/Xslope was determined from simulated reference beam location.

Cross-slope: Dynamic vs GT

Pavemetrics

Mean XSlopeErr = 0.07deg
Mean XSlopeErr = 0.13 %

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



Slope: Dynamic vs GT

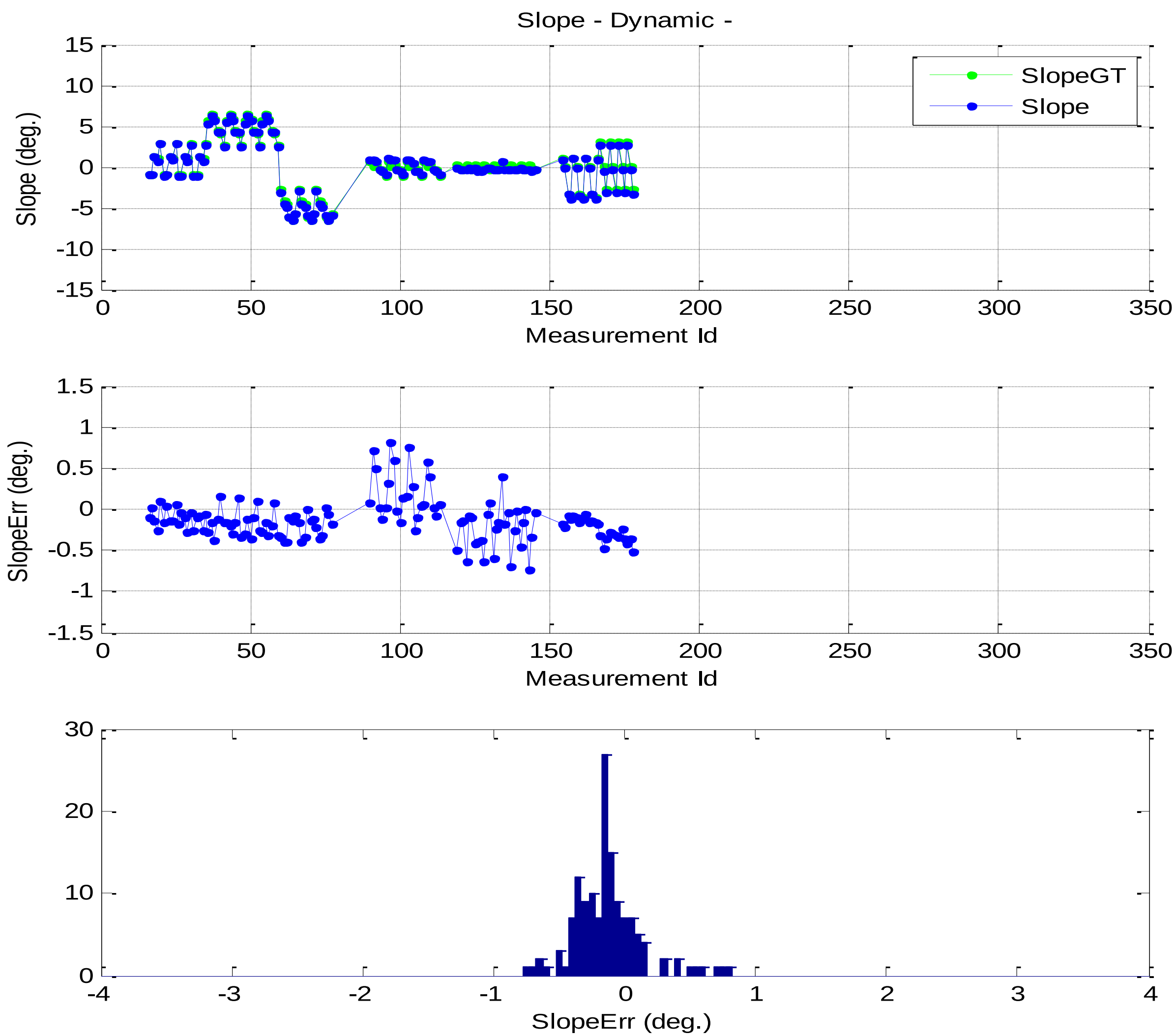
Pavemetrics

Mean SlopeErr = 0.13deg.

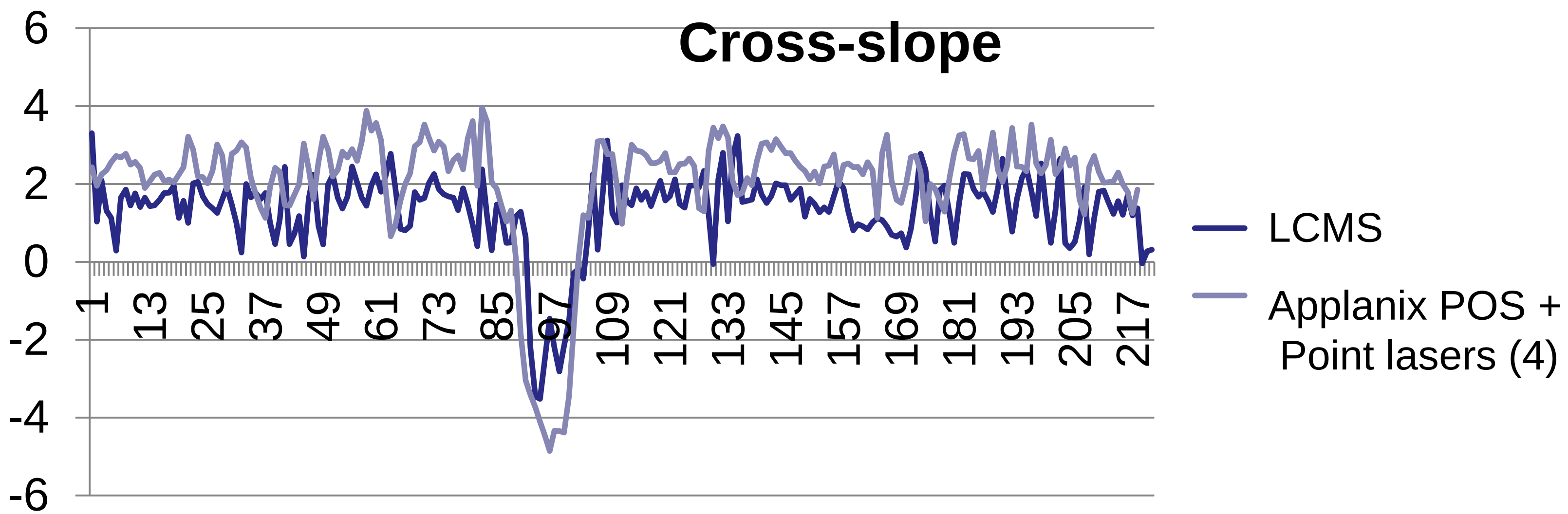
Mean SlopeErr = 0.25%

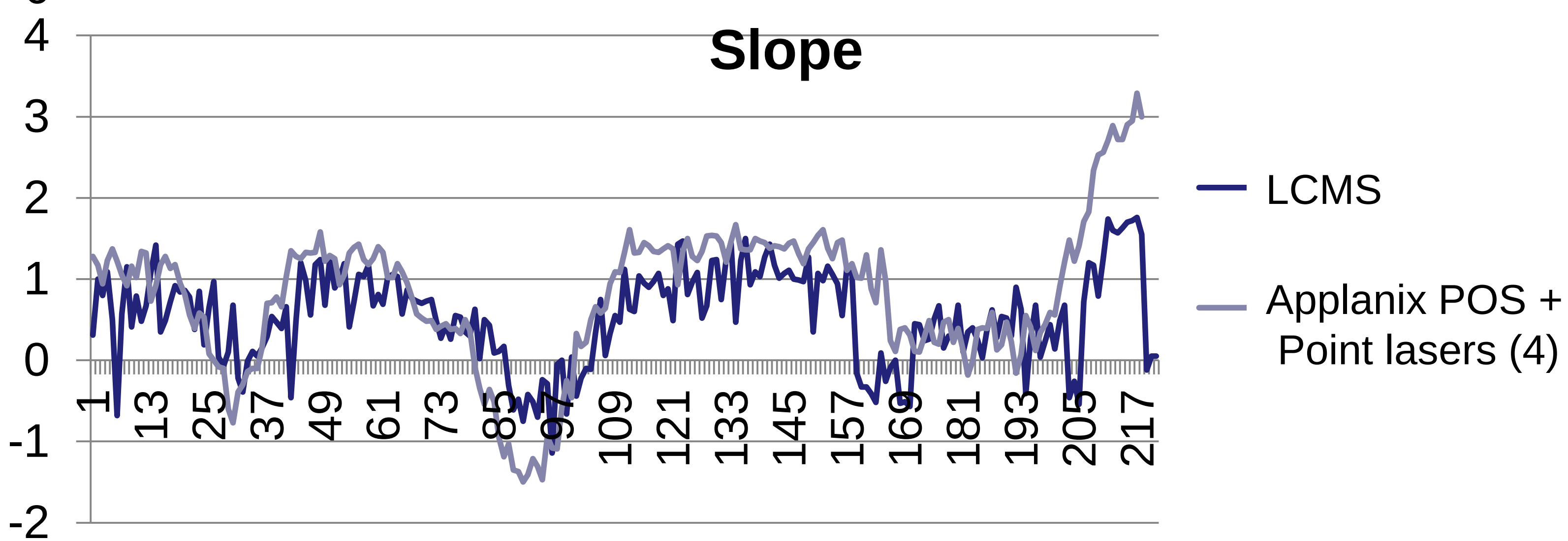
Std Dev. SlopeErr = 0.26deg.

Std Dev. SlopeErr = 0.46%



Road tests - Geometry

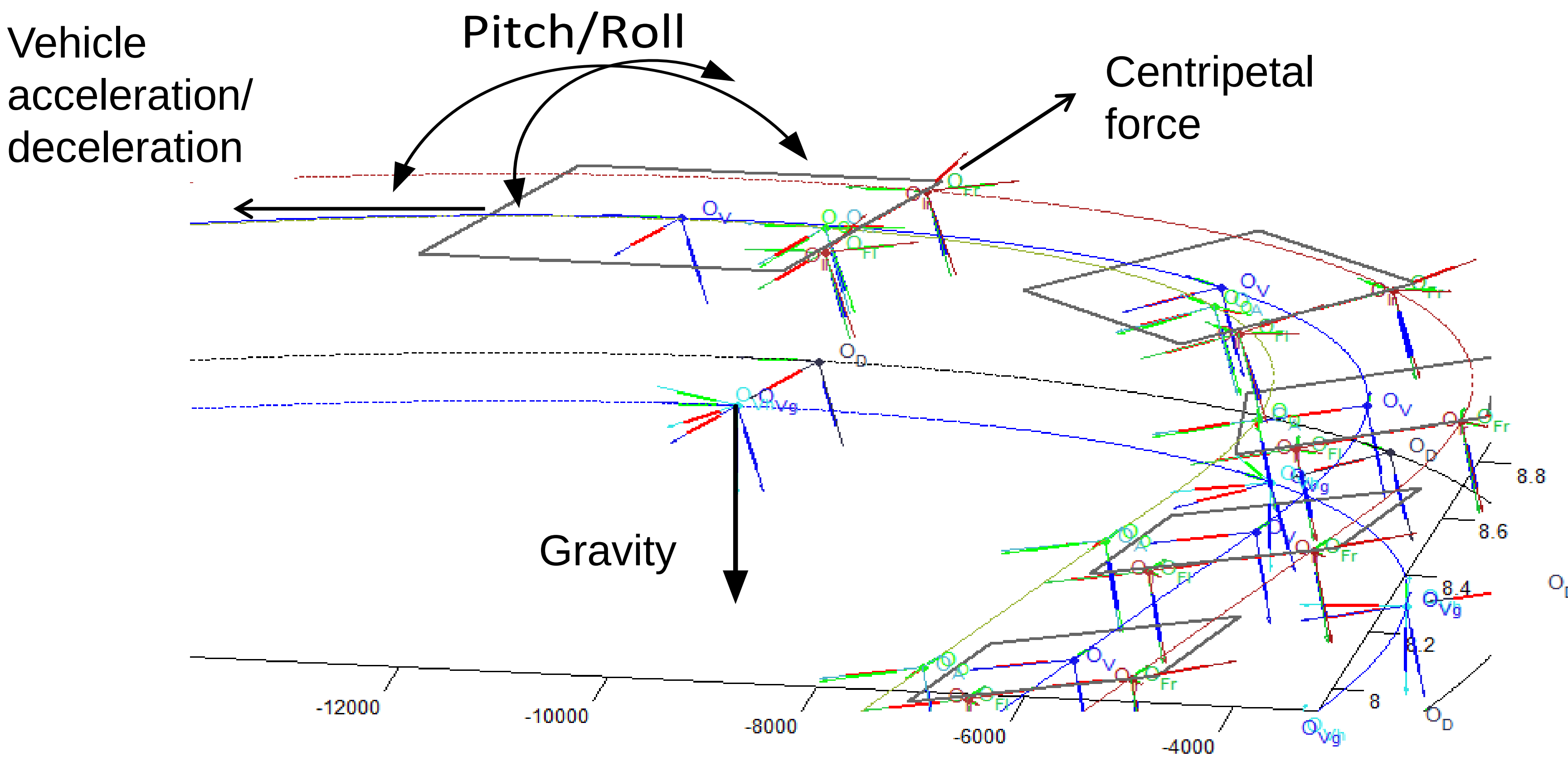




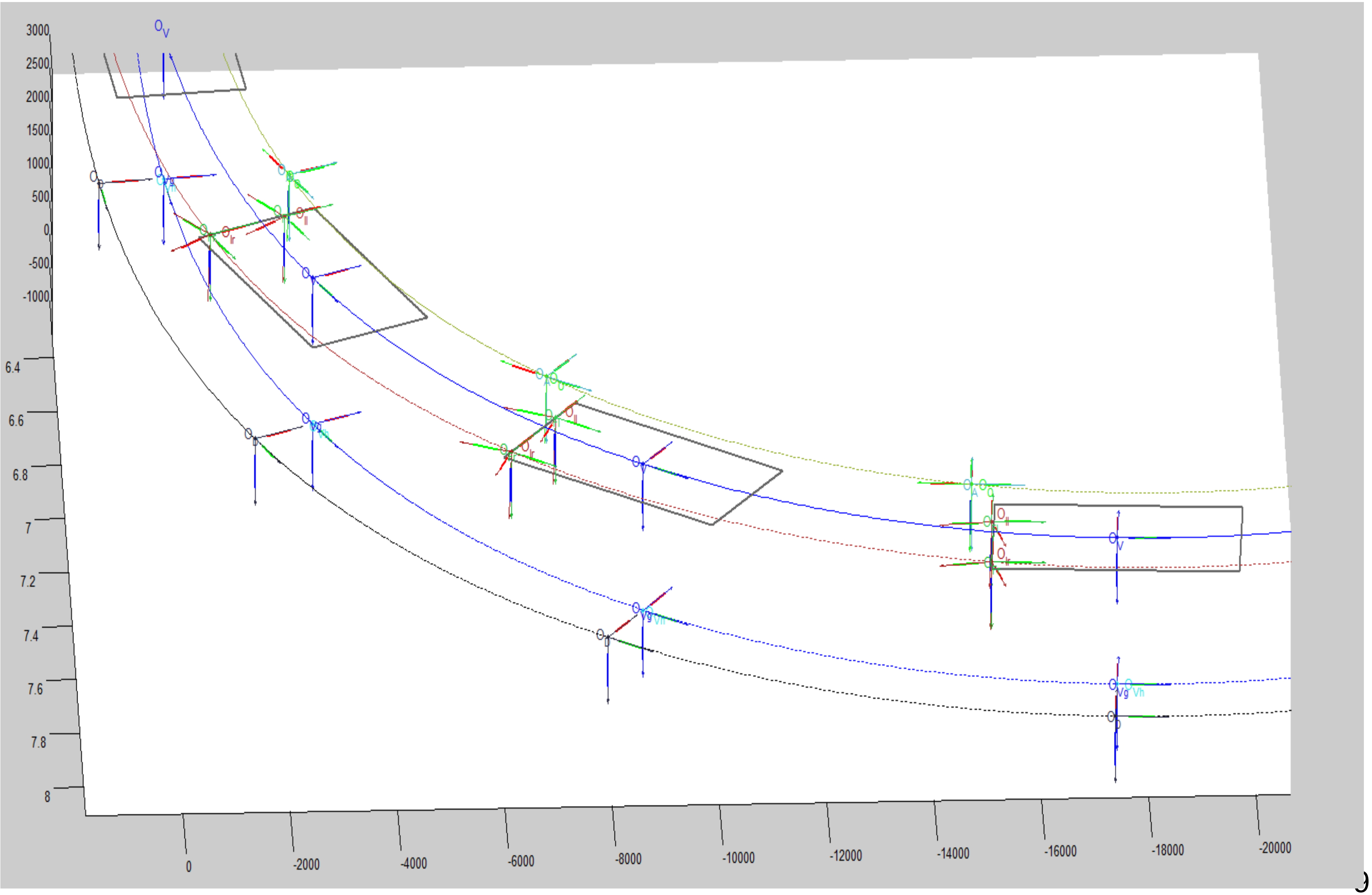
Pavemetrics

Terrain Mapping

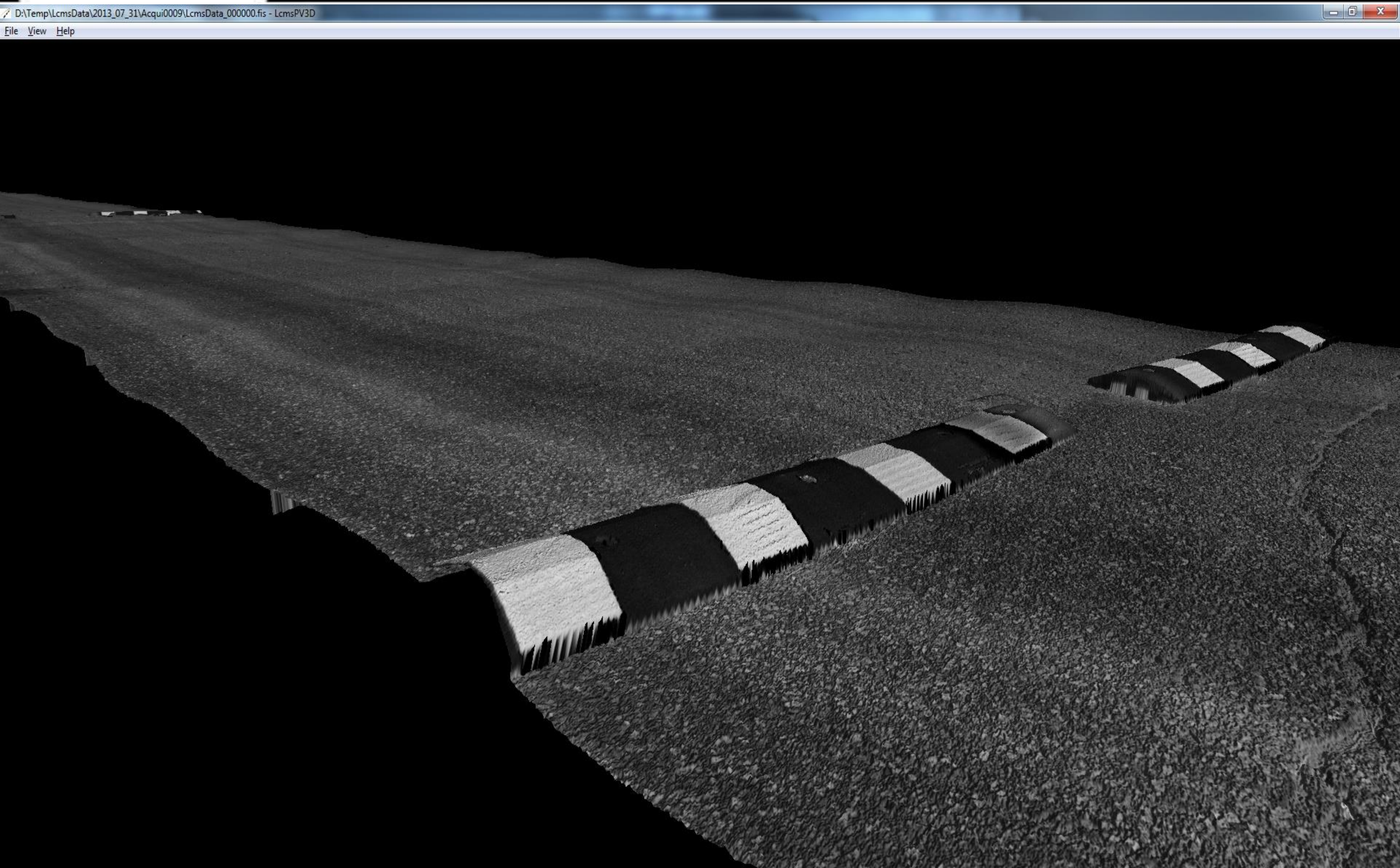
Complex Vehicle Dynamics



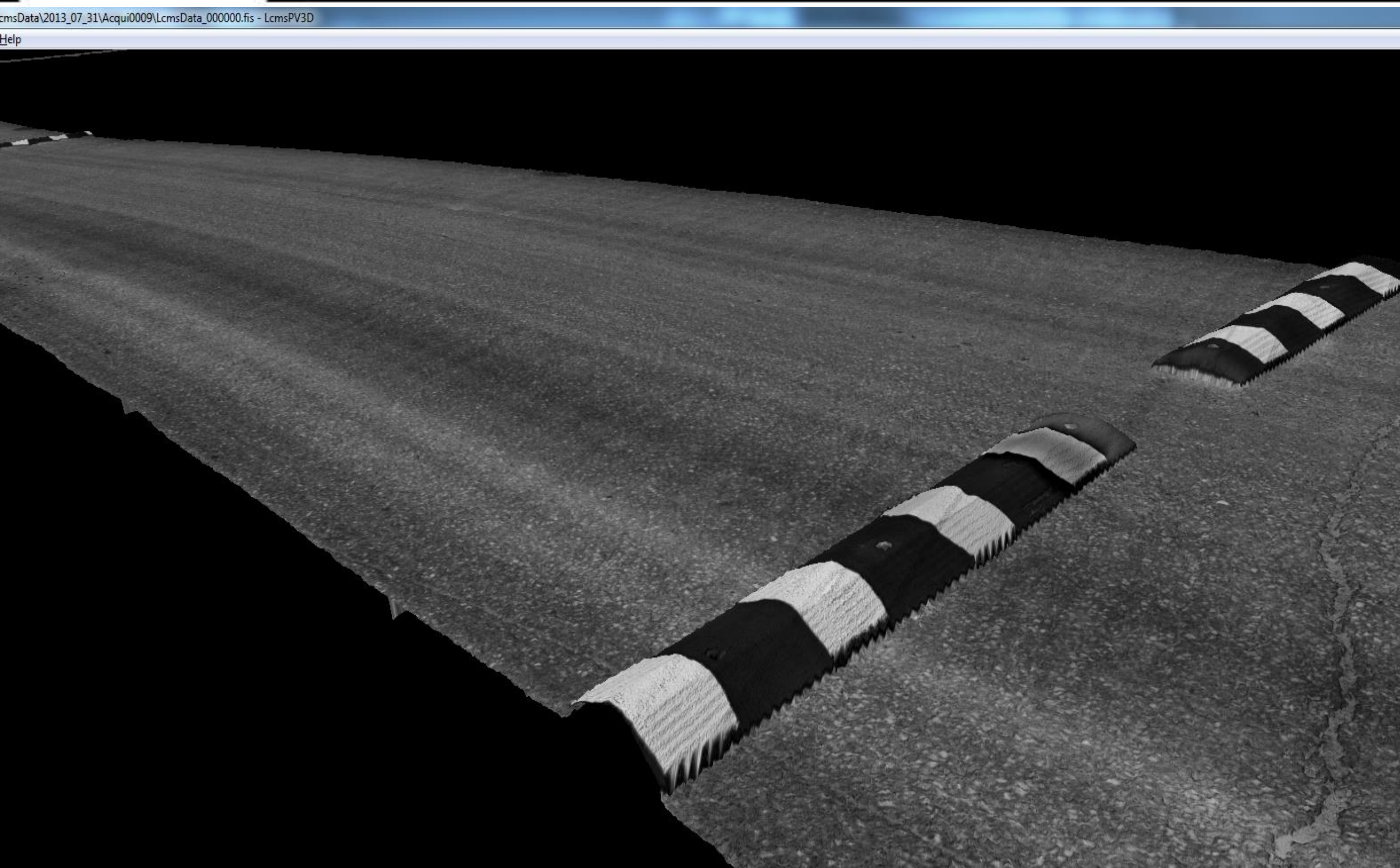
Final result – Vehicle track and DTM



3D Road Profile Before Dynamic Corrections



3D Road Profile After Dynamic Corrections



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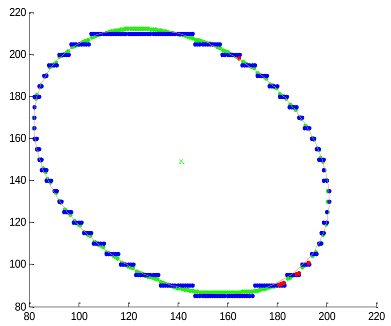
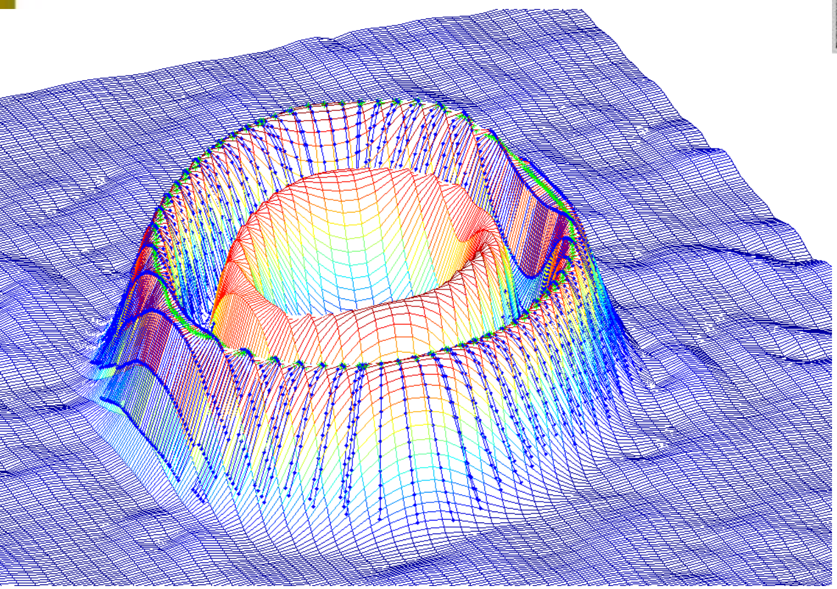
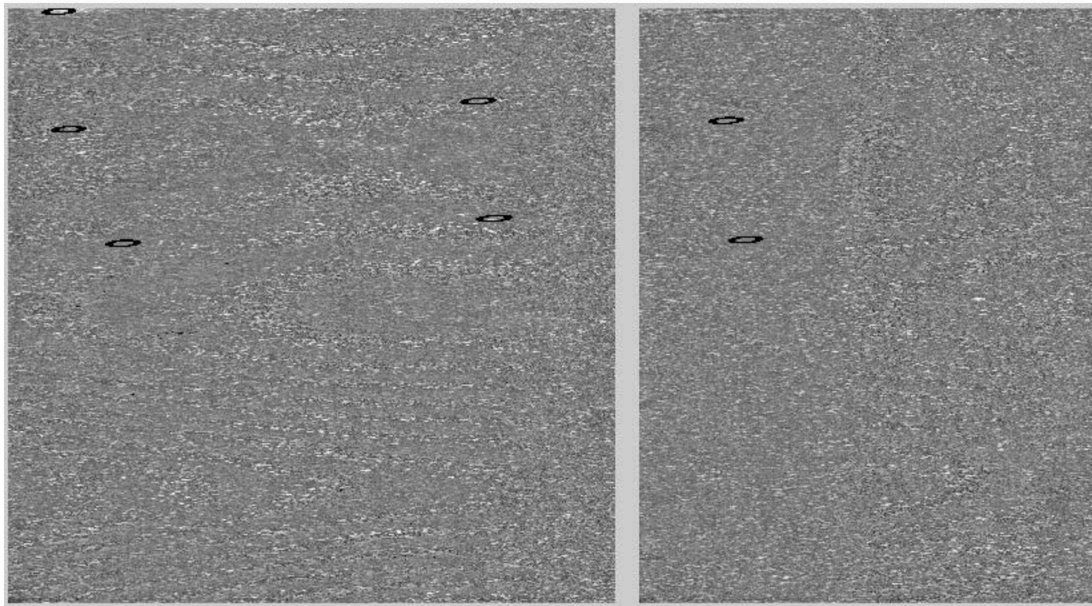
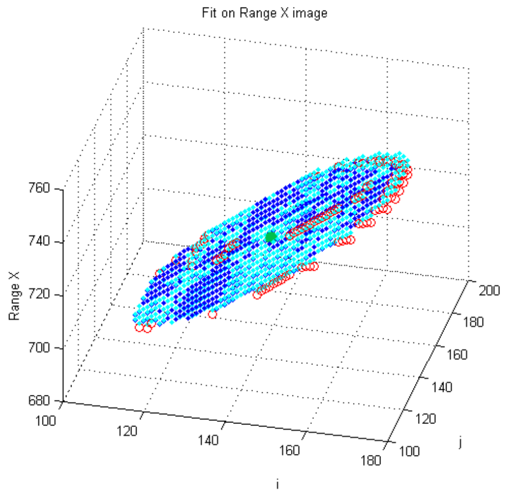
Field validation

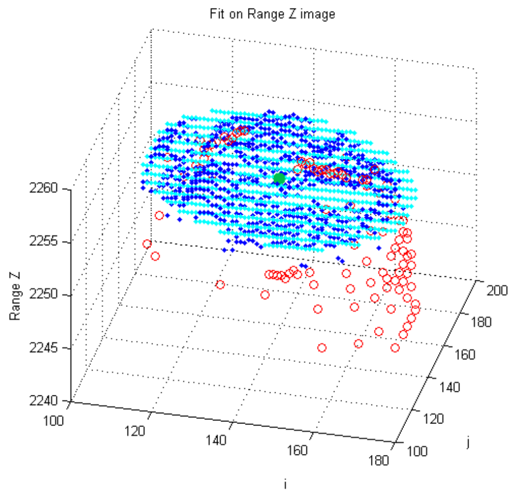
Field validation – Puck center evaluation



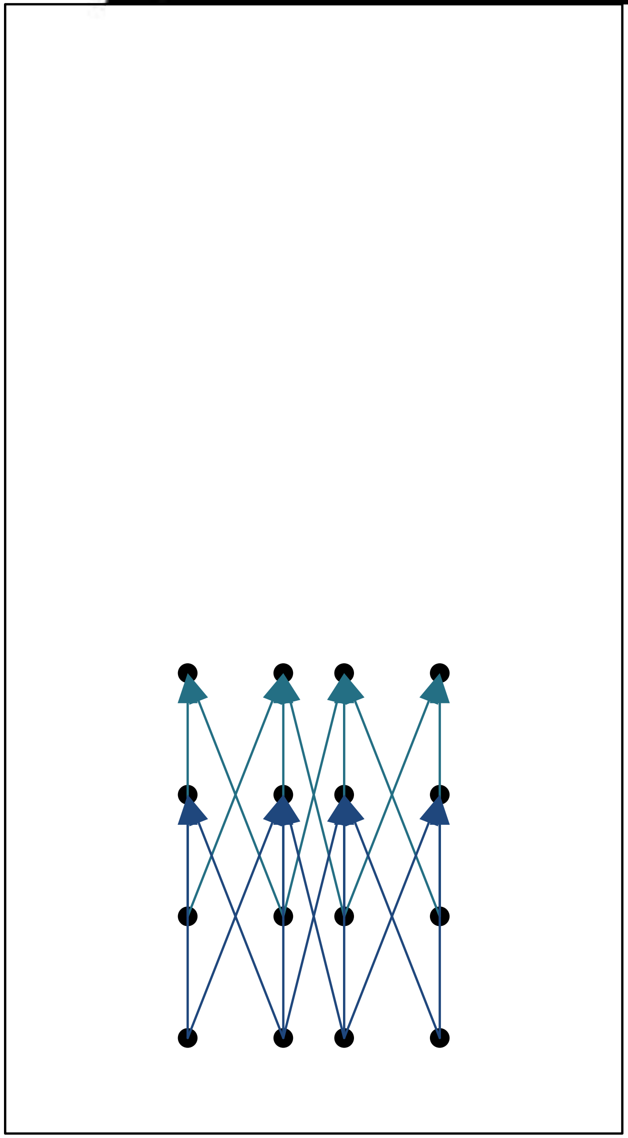




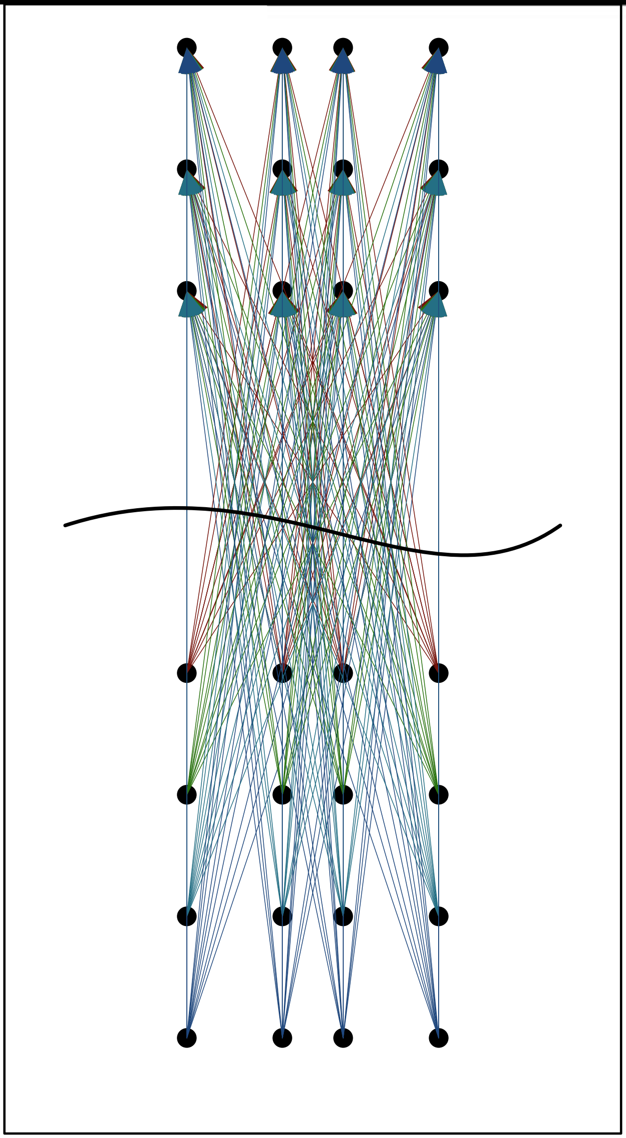




Field validation



Pairing pattern for the 4m test



Pairing pattern for the 67m test

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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% Inertiel - 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

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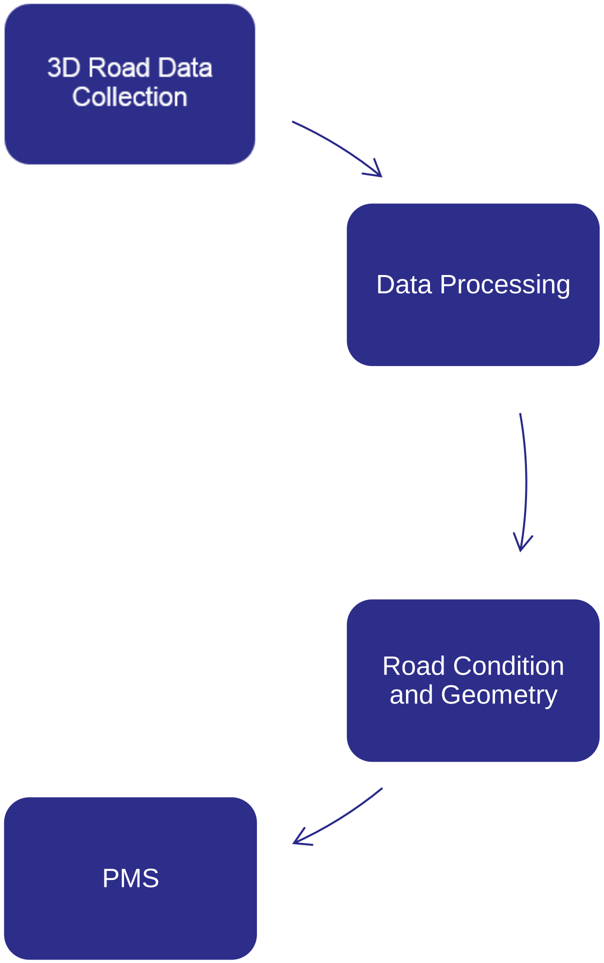
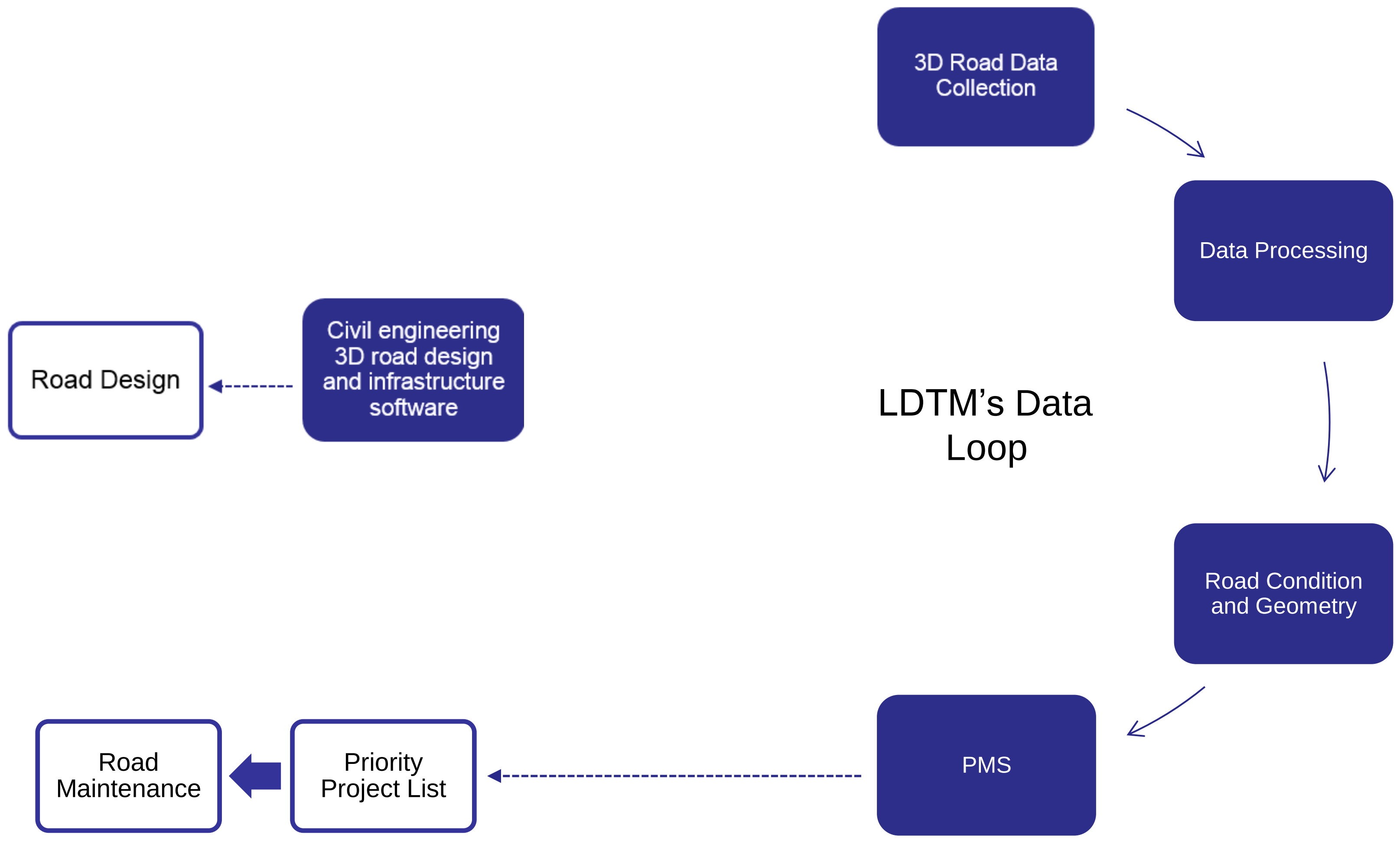
LDTM – Closing the Loop



LDTM – Closing the Loop



Road Profile Before Corrections

Road Profile After Geometric and Dynamic Corrections

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One Sensor; Many Outputs

Design
- Digital Terrain Models
- Automatic Breaklines

Safety
- Longitudinal Grade
- Cross Fall
- Horizontal Curvature
- Pavement Markings
- Foreign Object Debris

Inventory
- Linear Referencing
- GPS Tagging
- Pavement Type
- Pavement Length
- Pavement Width

Pavement Management
- Pavement Images
- IRI
- Macro Texture
- Potholes
- Raveling
- Rutting
- Longitudinal Cracks
- Transverse Cracks
- Alligator Cracking
- Sealed cracks
- Joint Faulting
- Transverse Profile

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Any Questions?

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