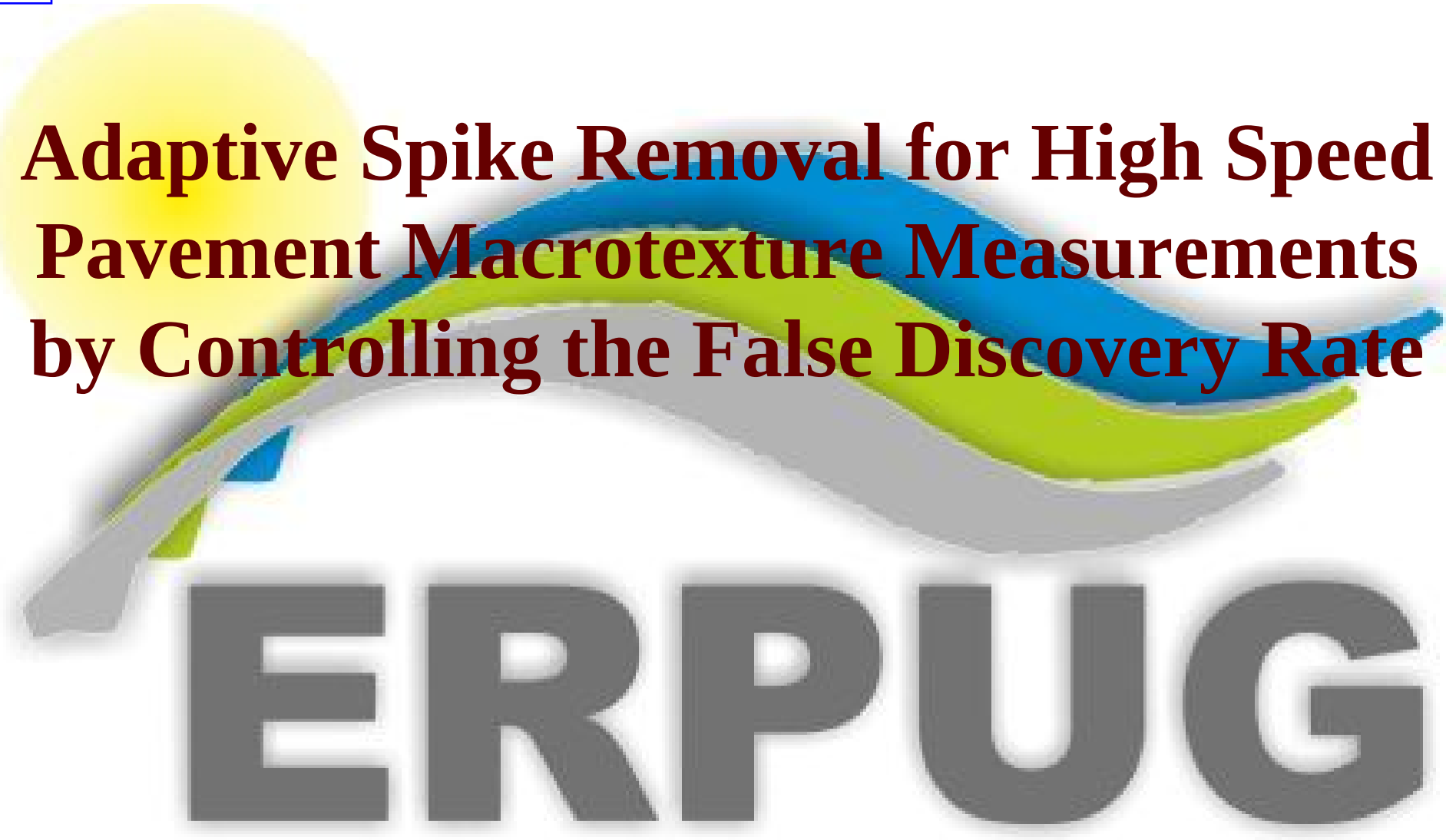
Home Menu

Adaptive Spike Removal for High Speed Pavement Macrotexture Measurements by Controlling the False Discovery Rate



Edgar de León Izeppi, Virginia Tech

Brussels, Belgium, October 24th 2014

Outline

- Background
- Problem statement
- Objectives
- Research approach
- Results
- Conclusions

- Samer Katicha, Gerardo Flintsch, and Daniel Mogrovejo TRB 15-4500

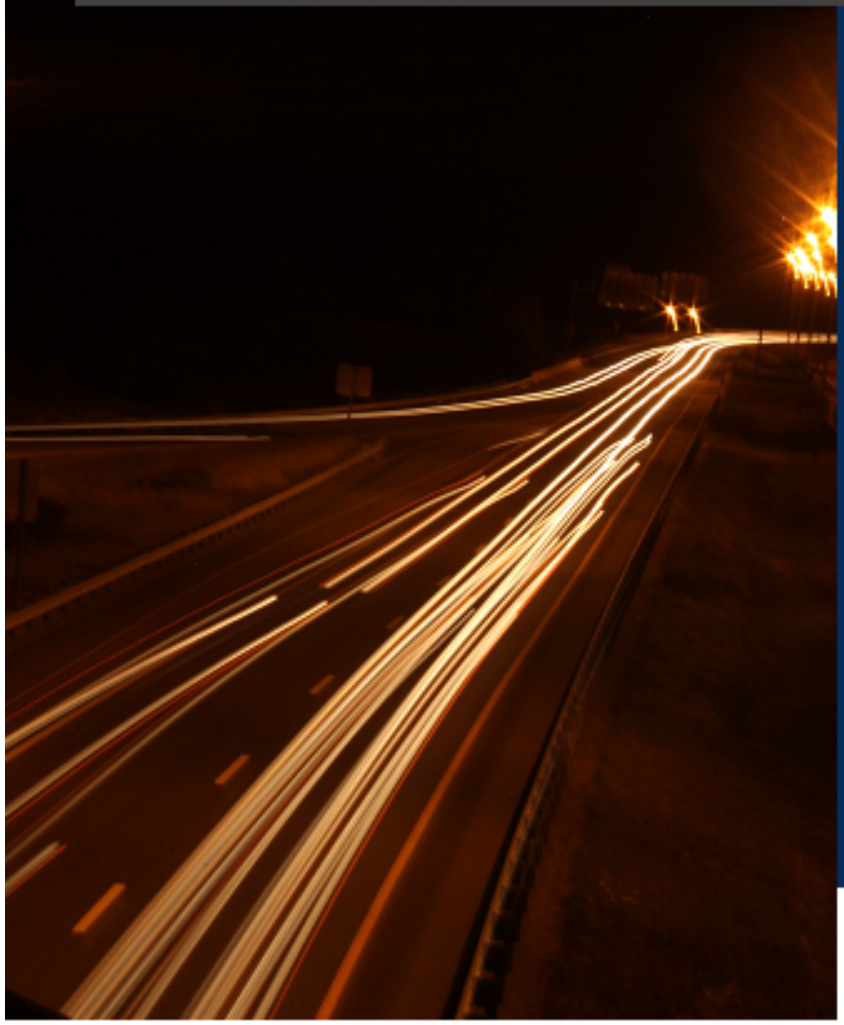
Background

- A standardized procedure for texture measurements at network level is not yet available
- Studies show that besides the traditional low-pass filtering, slope suppression, and drop out correction; the calculus of MPD values must be free of spikes

Federal Highway Administration

Solicitation Number: DTFH6114R00038

The Acceptance Testing and Demonstration of the Continuous Friction Measurement Equipment (CFME)



Volume I:

Technical Proposal

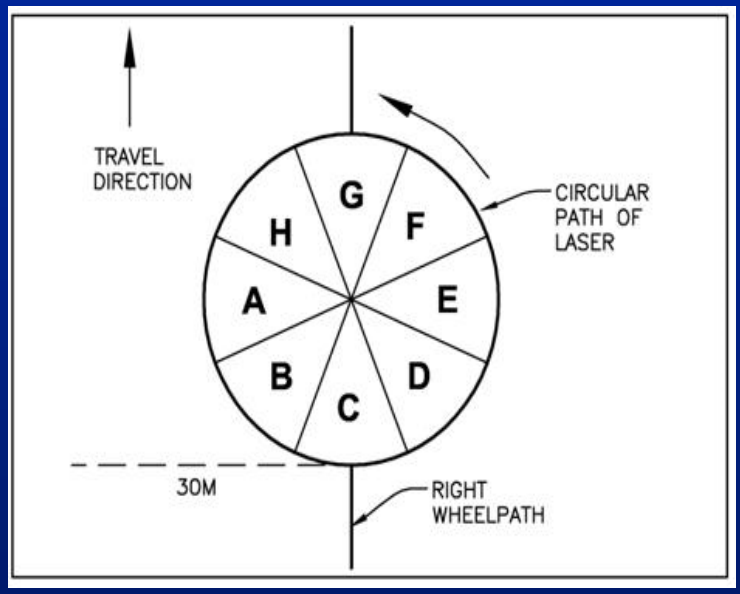
Submitted:

July 24, 2014

Virginia Tech
Transportation Institute

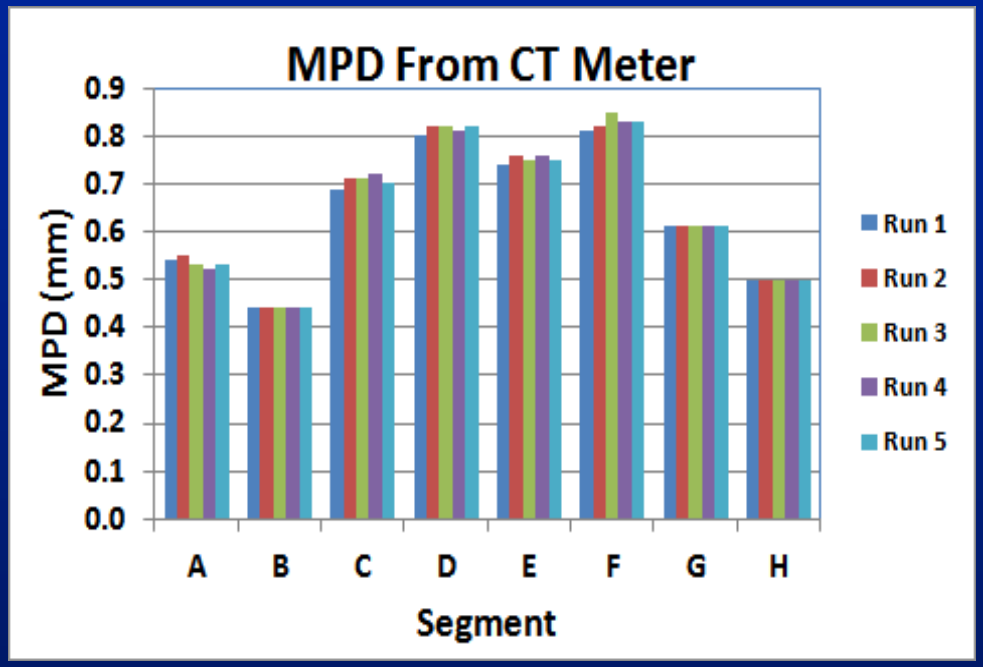
Sideway-Force Coefficient Routine Investigation Machine (SCRIM)

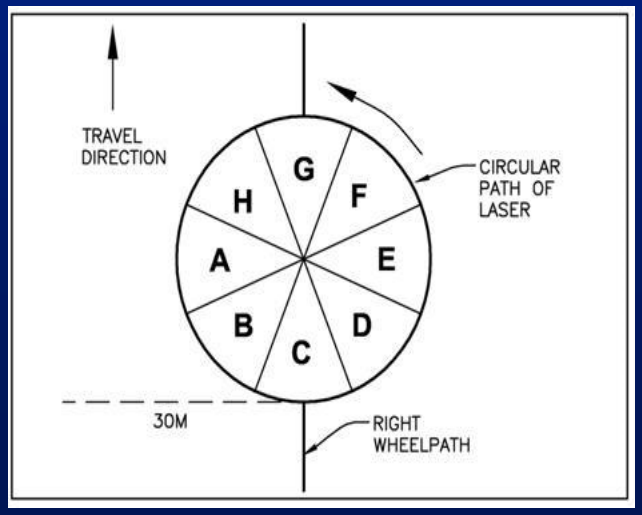
Presentation by Rohan Perera in RPUG 2013 San Antonio



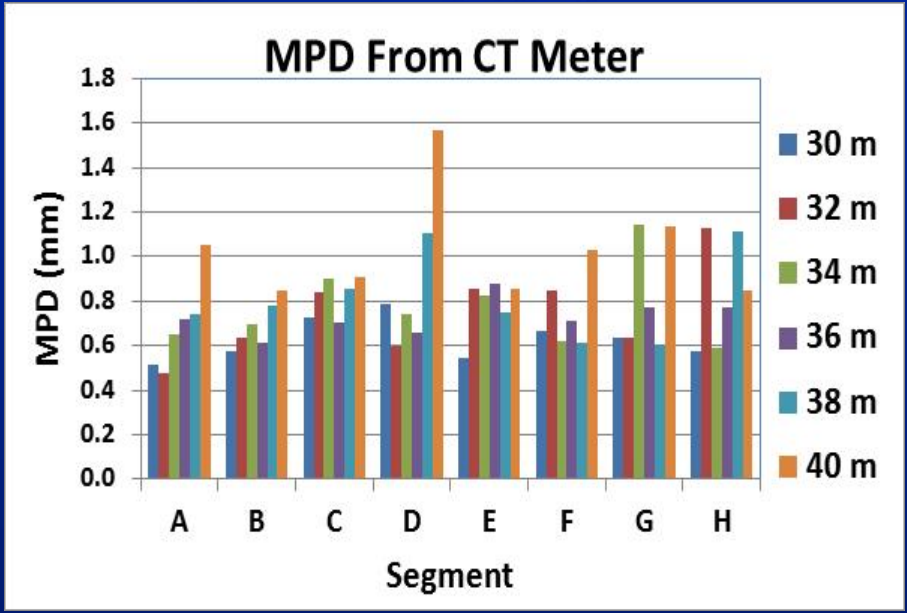
- **Sensor mounted on a rotating arm.**
- **Follows a circular path having a radius of 142 mm.**
- **Sample spacing = 0.87 mm, L = 892 mm (or eight 111.5 mm sectors)**

MPD From CT Meter – Repeatability Asphalt Section



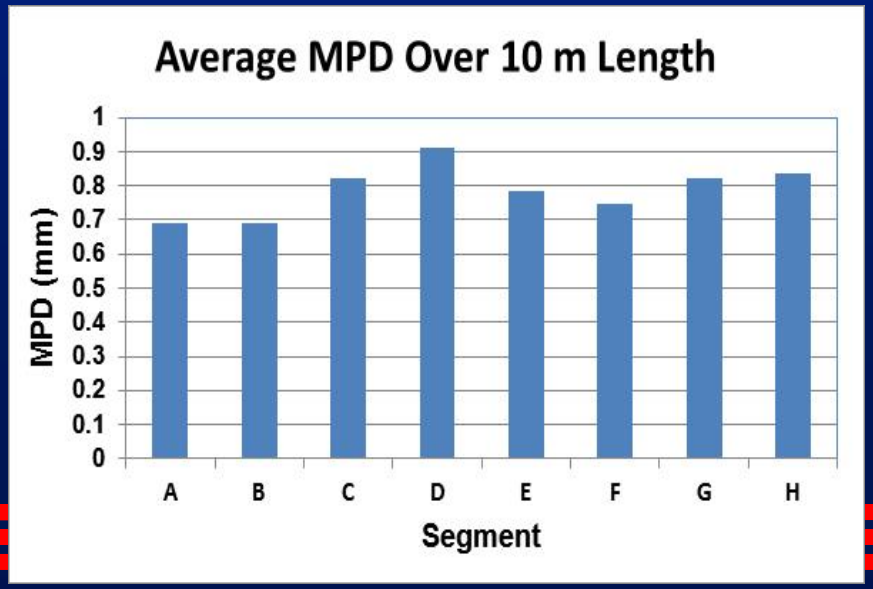


CT Meter - MPD on Asphalt Section at 2 m Intervals Along Right Wheelpath



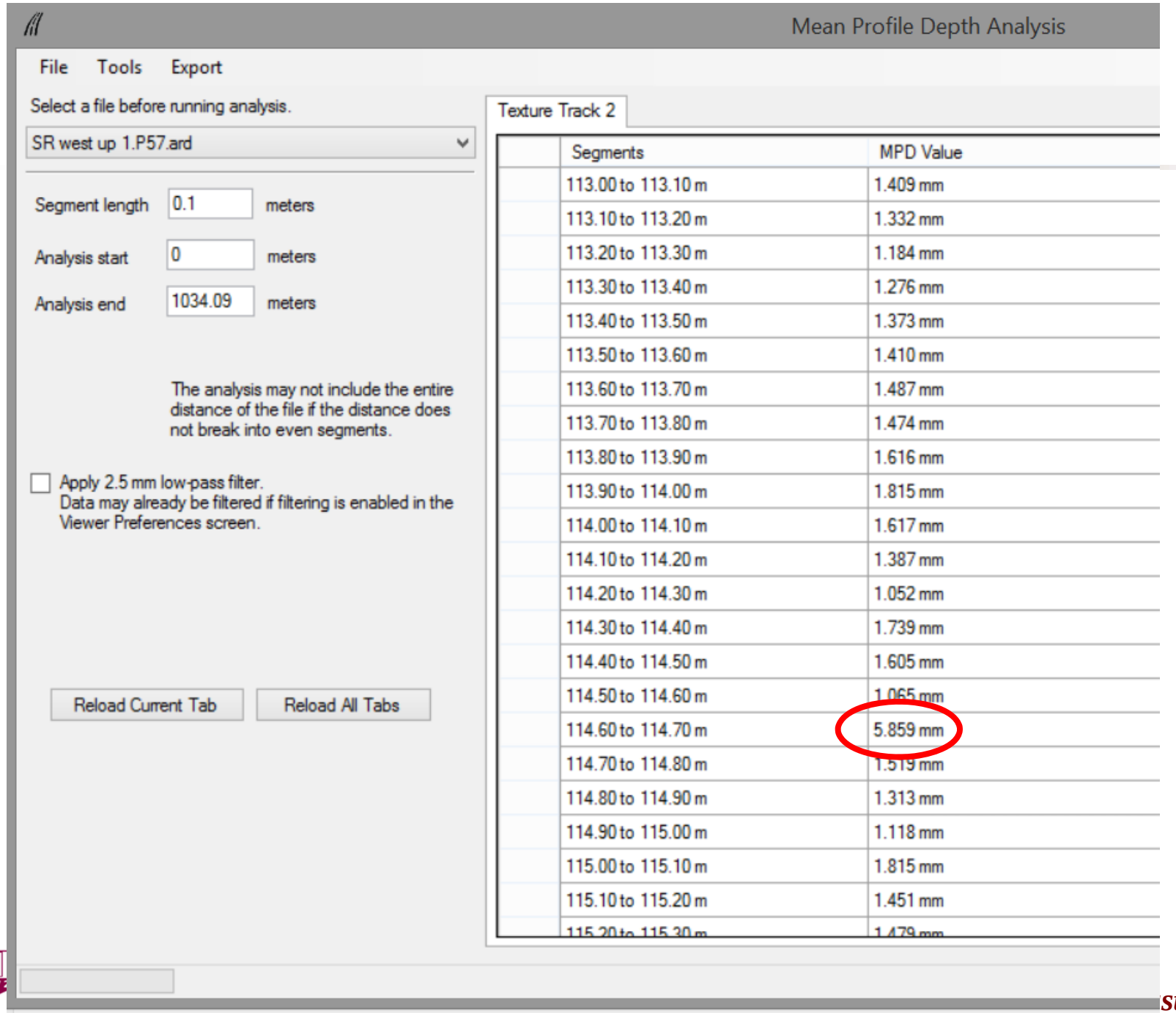
Location	Average
30 m	0.60
32 m	0.75
34 m	0.77
36 m	0.73
38 m	0.82
40 m	1.02
Average	0.78

Section	A	B	C	D	E	F	G	H
Average	0.69	0.69	0.81	0.91	0.76	0.74	0.82	0.84



Issues

- Improved procedures for verifying accuracy of macrotexture data collected by high-speed devices is necessary.
- High-frequency laser sensors may be noisy, thereby affecting MPD values.
- Single spikes were noted in the macrotexture data. Robust spike detection algorithms are needed.


Mean Profile Depth Analysis
File
Tools
Export
Select a file before running analysis.
SR west up 1.P57.ard
Segment length
0.1
meters
Analysis start
0
meters
Analysis end
1034.09
meters
The analysis may not include the entire distance of the file if the distance does not break into even segments.
Apply 2.5 mm low-pass filter.
Data may already be filtered if filtering is enabled in the Viewer Preferences screen.
Reload Current Tab
Reload All Tabs
Texture Track 2
Segments
MPD Value
113.00 to 113.10 m
1.409 mm
113.10 to 113.20 m
1.332 mm
113.20 to 113.30 m
1.184 mm
113.30 to 113.40 m
1.276 mm
113.40 to 113.50 m
1.373 mm
113.50 to 113.60 m
1.410 mm
113.60 to 113.70 m
1.487 mm
113.70 to 113.80 m
1.474 mm
113.80 to 113.90 m
1.616 mm
113.90 to 114.00 m
1.815 mm
114.00 to 114.10 m
1.617 mm
114.10 to 114.20 m
1.387 mm
114.20 to 114.30 m
1.052 mm
114.30 to 114.40 m
1.739 mm
114.40 to 114.50 m
1.605 mm
114.50 to 114.60 m
114.60 to 114.70 m
5.859 mm
114.70 to 114.80 m
114.80 to 114.90 m
1.313 mm
114.90 to 115.00 m
1.118 mm
115.00 to 115.10 m
1.815 mm
115.10 to 115.20 m
1.451 mm

Mean Profile Depth Analysis

ort

ng analysis.

meters

meters

.09 meters

analysis may not include the entire
nce of the file if the distance does
reak into even segments.

ss filter.
filtered if filtering is enabled in the
screen.

b Reload All Tabs

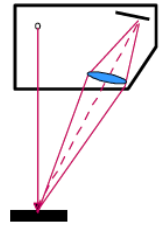
Texture Track 2

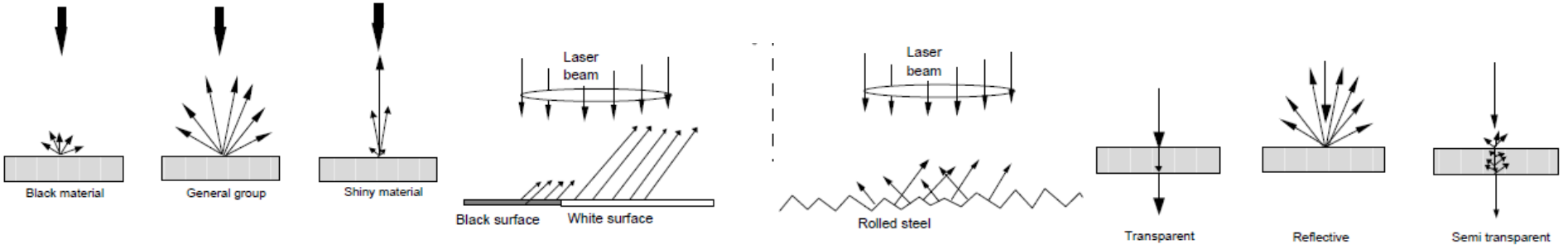
	Segments	MPD Value	MPD Std. Dev.
	882.80 to 882.90 m	1.452 mm	0.000 mm
	882.90 to 883.00 m	8.962 mm	0.000 mm
	883.00 to 883.10 m	1.581 mm	0.000 mm
	883.10 to 883.20 m	1.671 mm	0.000 mm
	883.20 to 883.30 m	1.190 mm	0.000 mm
	883.30 to 883.40 m	1.239 mm	0.000 mm
	883.40 to 883.50 m	1.364 mm	0.000 mm
	883.50 to 883.60 m	2.138 mm	0.000 mm
	883.60 to 883.70 m	2.093 mm	0.000 mm
	883.70 to 883.80 m	1.230 mm	0.000 mm
	883.80 to 883.90 m	2.065 mm	0.000 mm
▶	883.90 to 884.00 m	21.254 mm	0.000 mm
	884.00 to 884.10 m	1.706 mm	0.000 mm
	884.10 to 884.20 m	1.514 mm	0.000 mm
	884.20 to 884.30 m	1.308 mm	0.000 mm
	884.30 to 884.40 m	1.458 mm	0.000 mm
	884.40 to 884.50 m	1.328 mm	0.000 mm
	884.50 to 884.60 m	0.986 mm	0.000 mm
	884.60 to 884.70 m	1.286 mm	0.000 mm
	884.70 to 884.80 m	3.991 mm	0.000 mm
	884.80 to 884.90 m	0.602 mm	0.000 mm

Problem Statement

- **High-speed laser data are subjected to a variety of potential problems:**
  - ✓ **Shiny mirror-like surfaces**
  - ✓ **Black and/or shiny materials**
  - ✓ **Transparent materials**
  - ✓ **Others:**
    - ❑ **Temperature**
    - ❑ **Geometry**
    - ❑ **Bandwidth**
    - ❑ **Sample rate**

Change the amount and direction of incident light reflected to the receiving lens





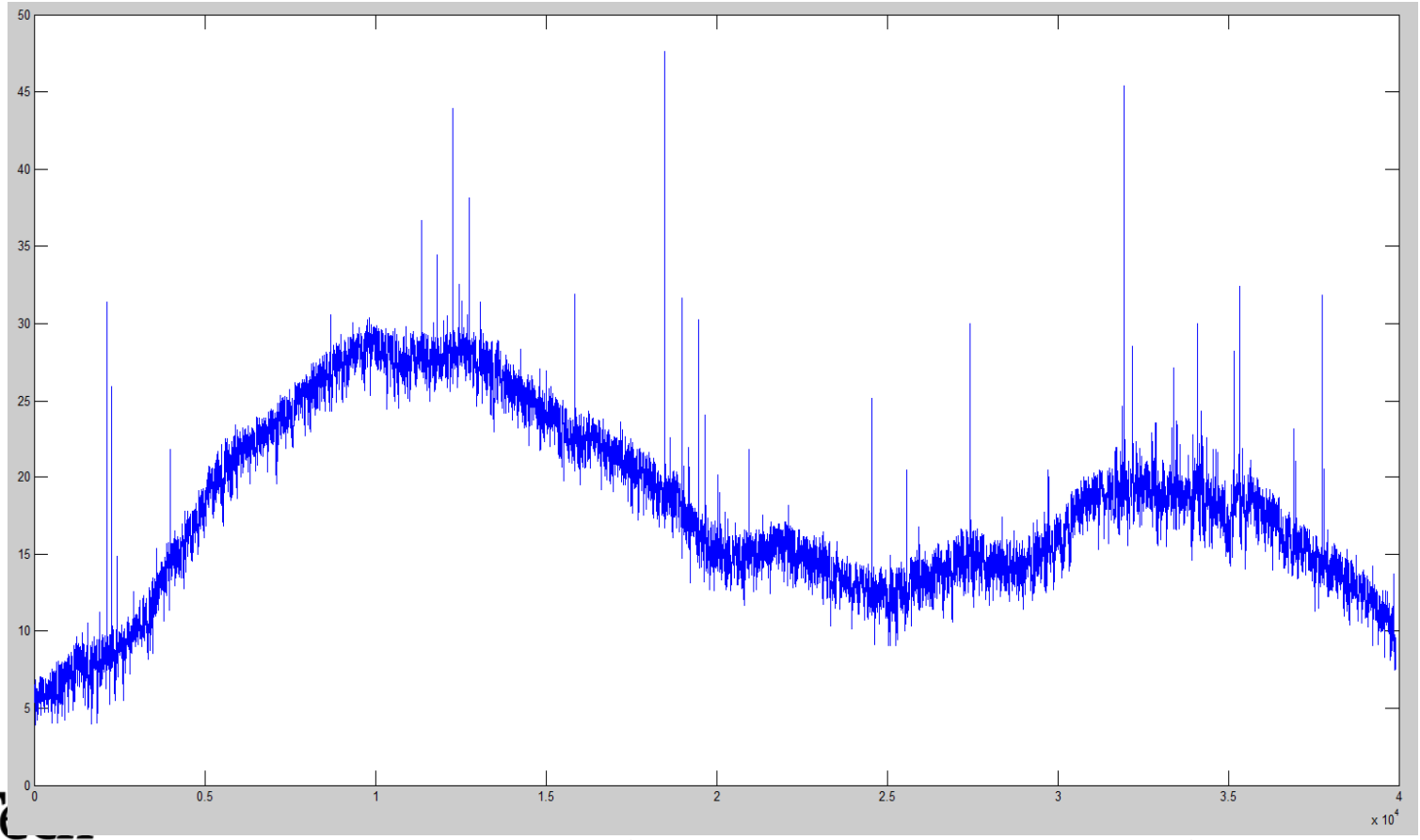
Illustrations from LMI Selcom User's manual

Problem Statement

- All laser measurements have spikes
- They create biases on the texture measurements.
- →Need to remove those spikes before computing good values for texture such as MPD.

Objective

- **Develop a method that can objectively identify and remove spikes.**



Methodology

- (a) Develop an innovative methodology that can objectively identify and remove the spikes.
- (b) Test this methodology with real data collected over different pavement surfaces
- (c) Calculate the MPD values and their associated statistical parameters, and
- (d) Validate the method by comparing the results with the ones obtained by the CTMeter(s), chosen as the standardized control method.

Research approach

- **Sites: 14 sections on Smart road.**

Section	Mix	Binder
A	SM-12.5D	PG 70-22
B	SM-9.5D	PG 70-22
C	SM-9.5E	PG 76-22
D	SM-9.5A	PG 64-22
E	SM-9.5D	PG 70-22
F	SM-9.5D	PG 70-22
G	SM-9.5D	PG 70-22
H	SM-9.5D	PG 70-22
I	SM-9.5A	PG 64-22
J	SM-9.5D	PG 70-22
K	OGFC	PG 76-22
L	SMA-12.5D	PG 70-22
VDOT Modified EP-5 *	Epoxi-(Silica, Basalt) concrete overlay	epoxy
SafeLane ™ *	3/8-in-think polymer-Limestone concrete overlay	epoxy

Research approach

- **Equipment: 2 CTMeters, 1 HSLD**

Successfully pre-calibrated

The HSLD has a laser spot with diameter of 0.2 mm and a sampling frequency of 64 kHz

Research approach

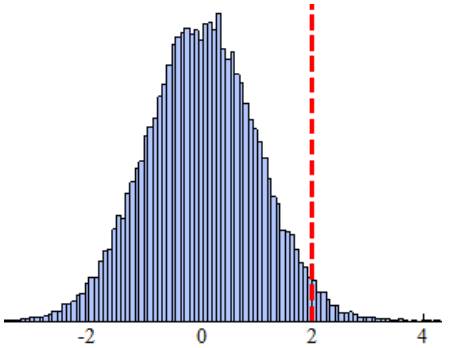
- **Methodology:**
  - ✓ **First, determines the distribution of texture measurements, and**
  - ✓ **Second, determines which measurements are outliers and therefore spikes (determine a threshold)**

Research approach

- **Methodology (distribution):**
  - ✓ **Normal distribution with a fixed 3 sigma threshold to define outliers?**
    - **Real texture data do not follow a normal distribution**
  - ✓ **Proposed approach → Generalized Gaussian Distributions (GGD)**
  - ✓ **Data adaptive threshold based on FDR (False Discovery Rate)**

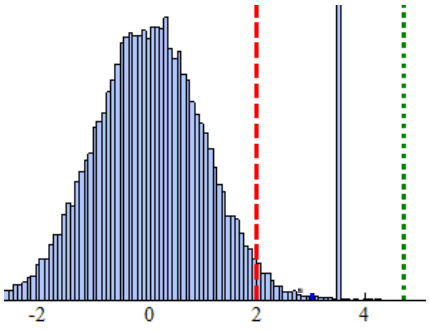
Research approach

- **Methodology (threshold):**
  - ✓ **Normal distribution with a fixed 2 or 3 sigma threshold to define outliers?**
    - **2 sigma (which approximately covers 95 % of the distribution) or 3 sigma (about 99 %).**
    - **For example, 20 m pavement section, data every 0.5 mm → 40,000 measurements. 2 sigma threshold → on average, 2,000 of the collected measurements will be identified as spikes. Even with using 3 sigma as a threshold, 400 measurements will be identified.**
    - **They fail to address one crucial aspect of high speed texture measurement – the large amount of data collected.**



Research approach

- **Methodology (threshold):**
  - ✓ **Proposed approach: adjustment to the threshold.**
  - ✓ **A possible approach: The Bonferroni correction:**
    - **divide the p-value of the significance test by the number of observations.**
    - **i.e. for the 95% interval, the p-value is 0.05; with 40,000 measurements:**
    - **Bonferroni correction adjusts the p-value of 0.05 to 0.00000125 (=0.05/40,000).**
    - **While this will solve the problem of wrongly identifying outliers, it will miss detecting outliers that are just under the Bonferroni threshold.**



  - ✓ **To address this shortcomings: FDR approach which adapts to the data**

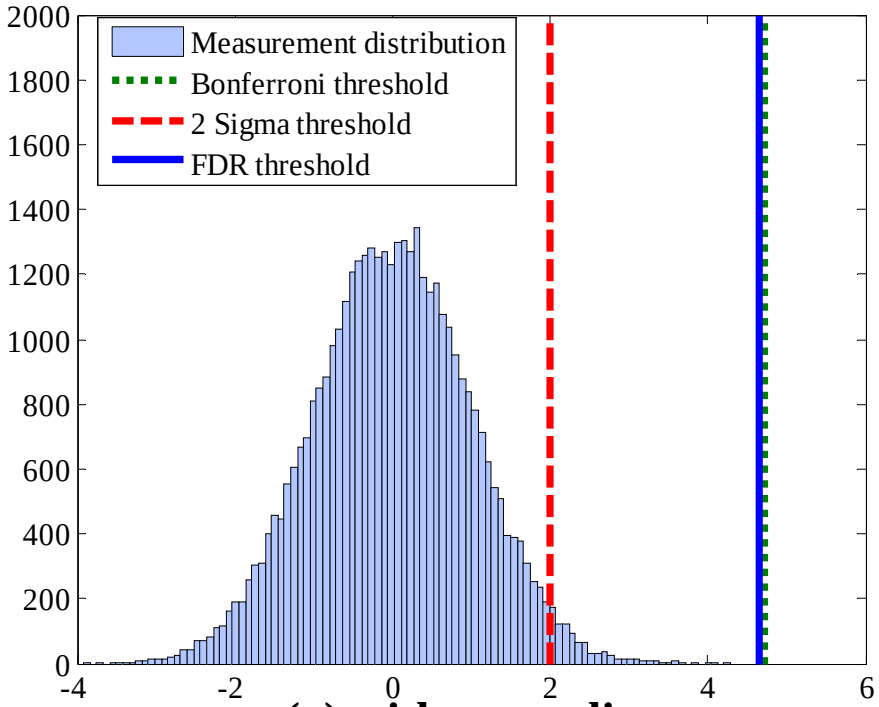
Research approach

- **Methodology (threshold):**
  - ✓ **FDR: Controls the proportion of wrongly identified spikes among all identified spikes**
    - *n* measurements of which n_0 are not spikes and 1-n_0 are spikes, calculate the p-values of all *n* measurements
    - Reorder the p-values in increasing order $p_1 \le \ldots \le p_i \le \ldots \le p_n$
    - Select a q value at which to control the FDR (e.g. 0.01, 0.05, or 0.1). (q is the prop. of false spikes among all spikes)
    - Let *k* be the maximum *i* such that: $p_i \le \frac{i}{n} q$
    - Spikes are identified as all measurements whose p-value is $\le p_k$

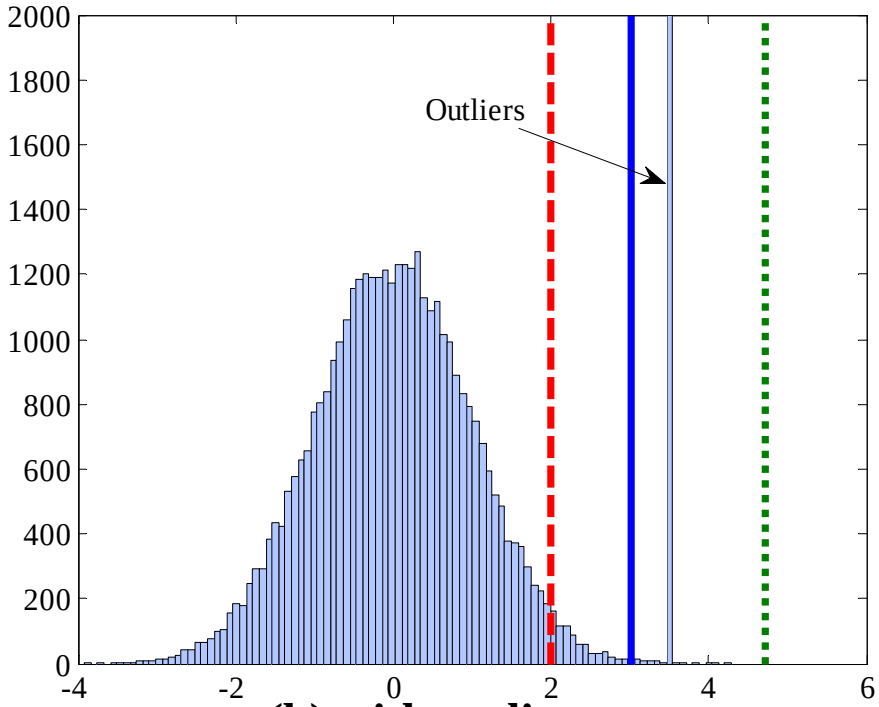
$$FDR \le \frac{n_0}{n} q \le q$$

Research approach

- **Methodology (threshold):**



(a) without outliers



(b) with outliers.

Threshold selection. The 2 sigma and Bonferroni thresholds are constant while the FDR threshold adapts to the measurements

Research approach

- **GGD:**

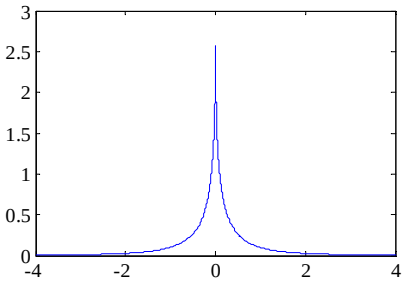
$$p(x) = \frac{\beta}{2\alpha\Gamma(1/\beta)} \exp\left(-\left(\frac{|x-\mu|}{\alpha}\right)^{\beta}\right)$$

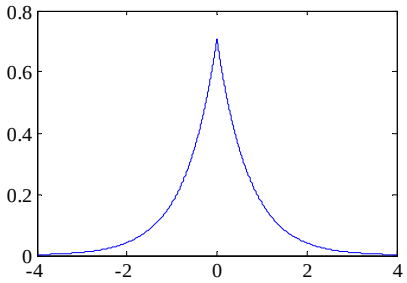
β is a shape parameter (positive),

α is a scale parameter related to the variance (positive), and

μ is a location parameter (average).

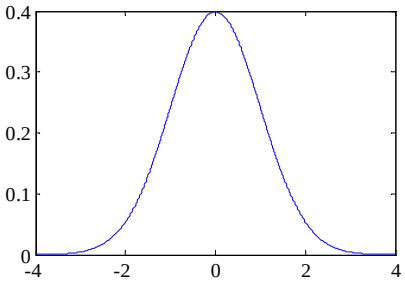
β = 0.5

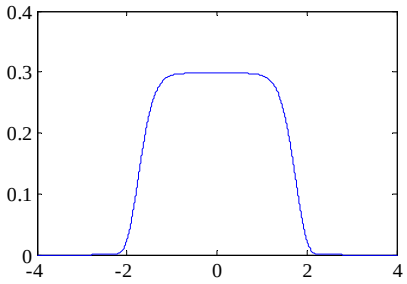




β = 1
(Laplace distribution)

β = 2
(normal distribution)

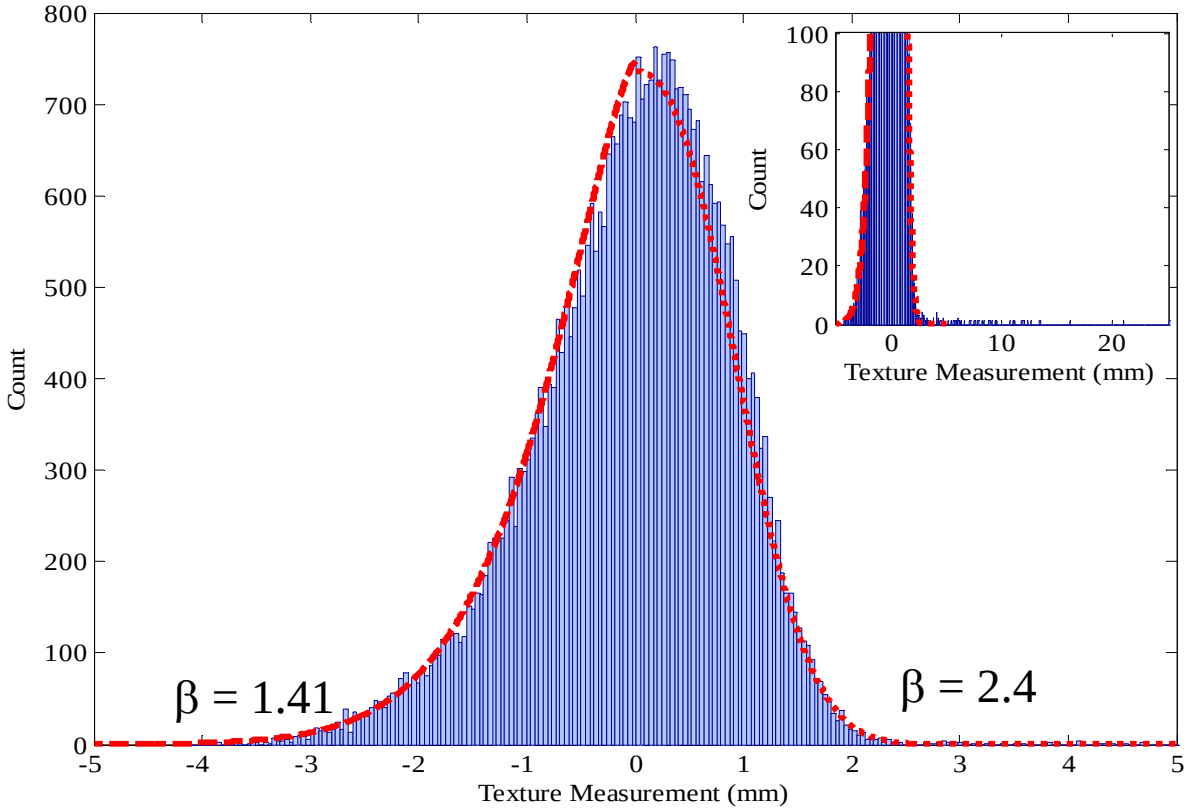




β = 8

Research approach

To obtain the parameter β, the distribution is fitted (i.e.) to the 90th to 97th percentiles of the data.



because <u>the tail</u> of the distribution <u>determines whether a data point is an outlier or not</u> and therefore the fit should be done to the higher percentiles of the data.
but NOT higher than 97th

A 97 % limit ensures that the GGD fit will be robust to the presence of as much as 3 % of outlier data

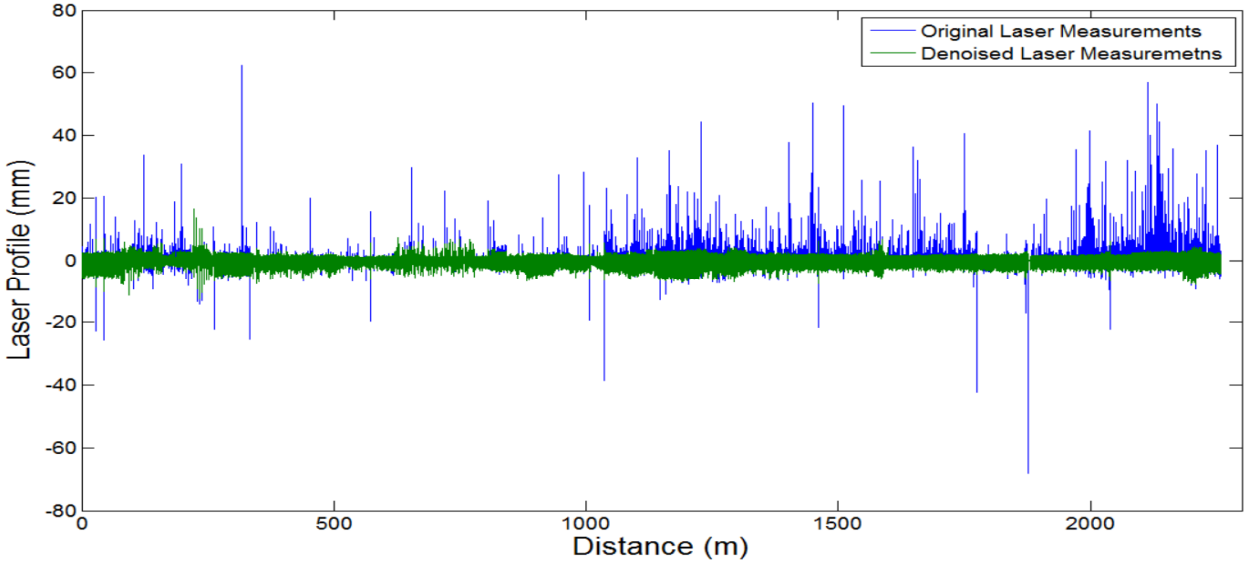
Results

- Ten randomly taken measurements with each CTMeter were made for every section along the left wheel path.
- Ten Runs along the same wheel path were made with the HSLD.
  - ✓ The dynamic measurements were processed using the proposed denoising methodology, with a chosen False Discovery Rate of 0.1, and a range of 0.9 to 0.95

Results

- Found 6,034 spikes , over 4,517,952 measurements, → 0.13%
- Similar percentages were found for the other runs.
- → The denoising method found on average one significant spike for approximately every 750 data points (300 to 400 mm).
- In other words the method successfully removes spikes that otherwise would affect, on average, one third of the calculated continuous MPD results.

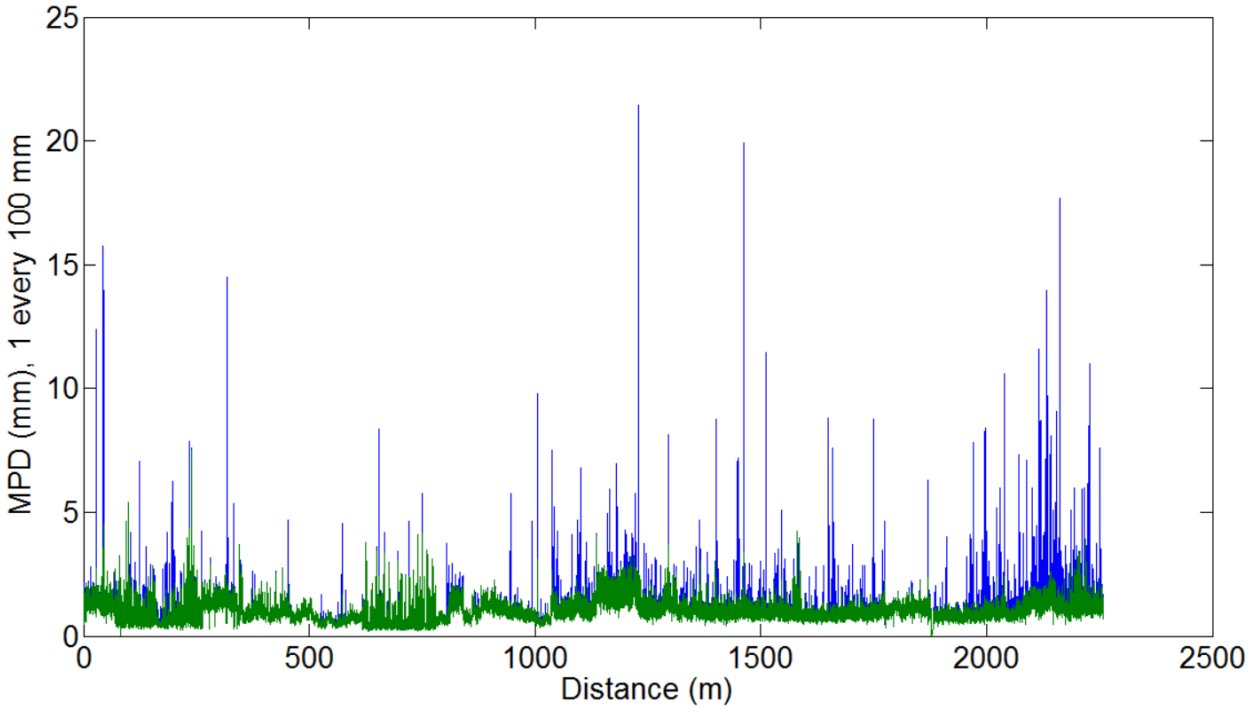
Profile Measurements from the HSLD, with and without Spikes (i.e. run 3)



Results

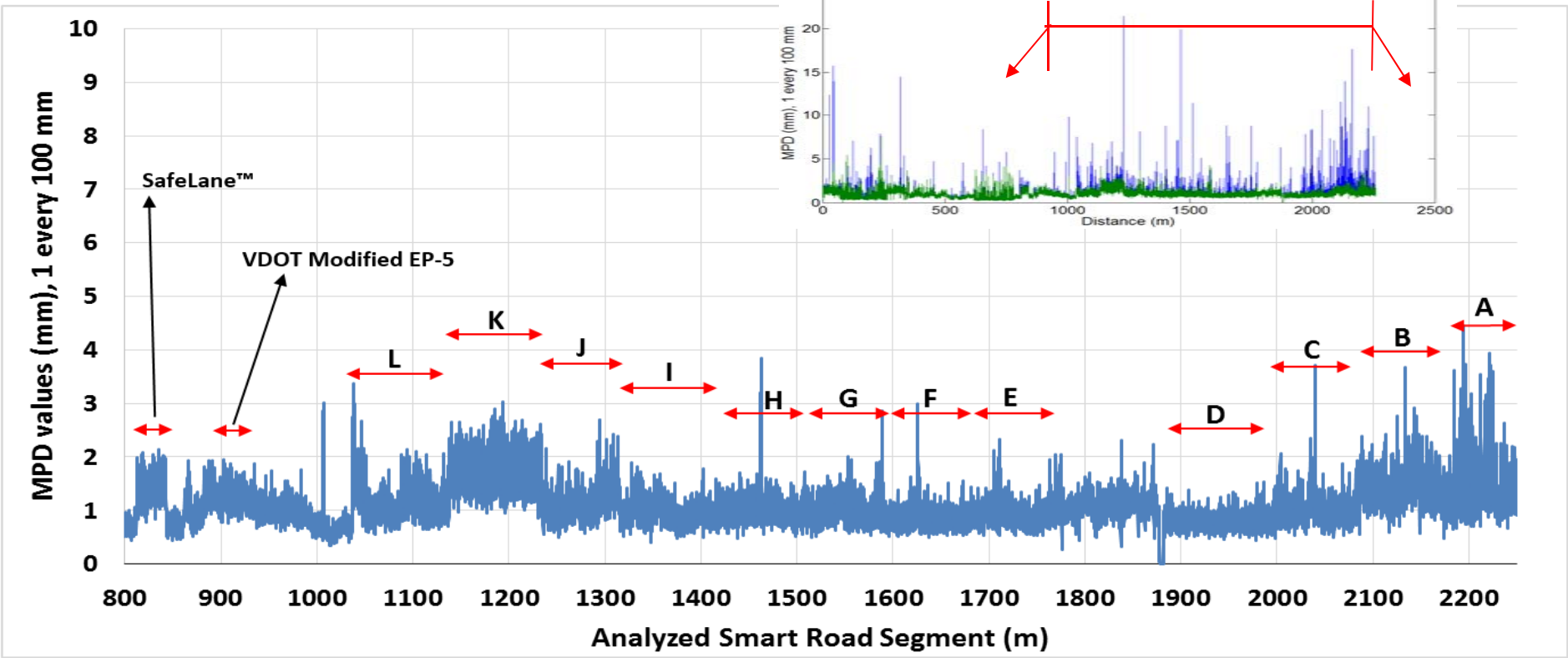
- The MPD calculations using the ASTM E1845-09
- MPD measurements (one value every 100 mm)

MPD values calculated with the original (blue) and denoised (green) data (i.e. run 3)

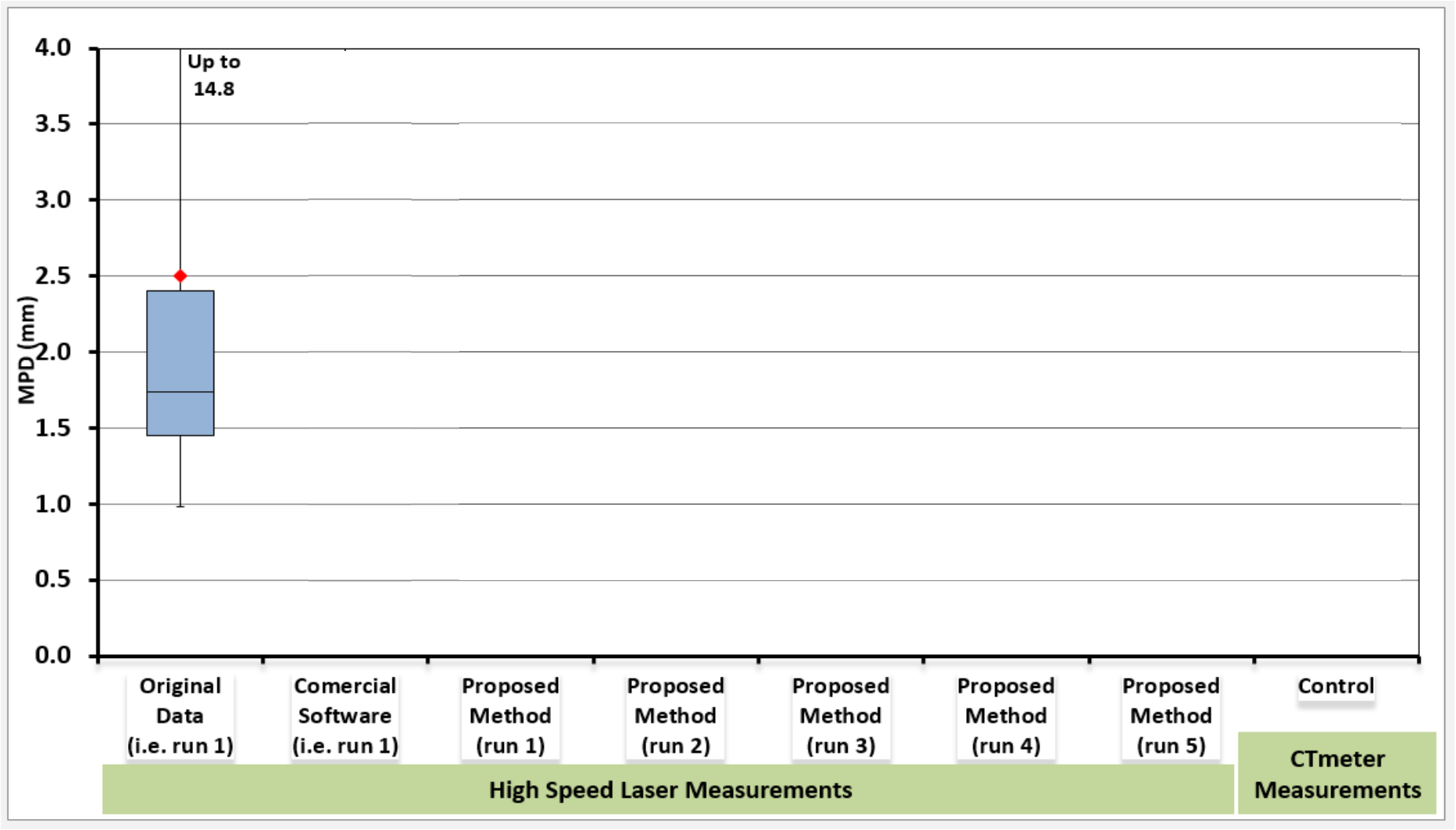


Results

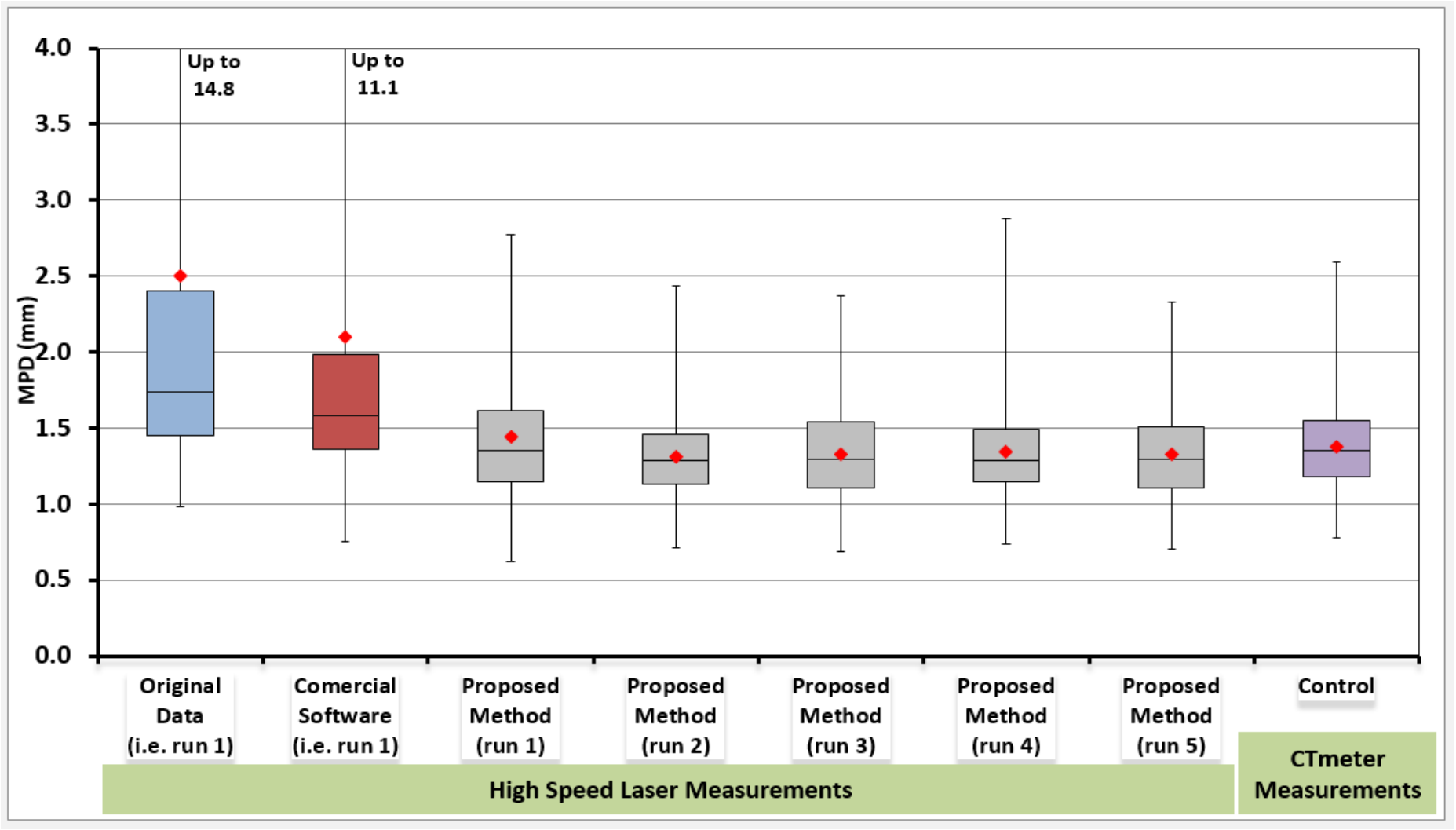
- The MPD calculations using the ASTM E1845-09
- MPD measurements (one value every 100 mm)



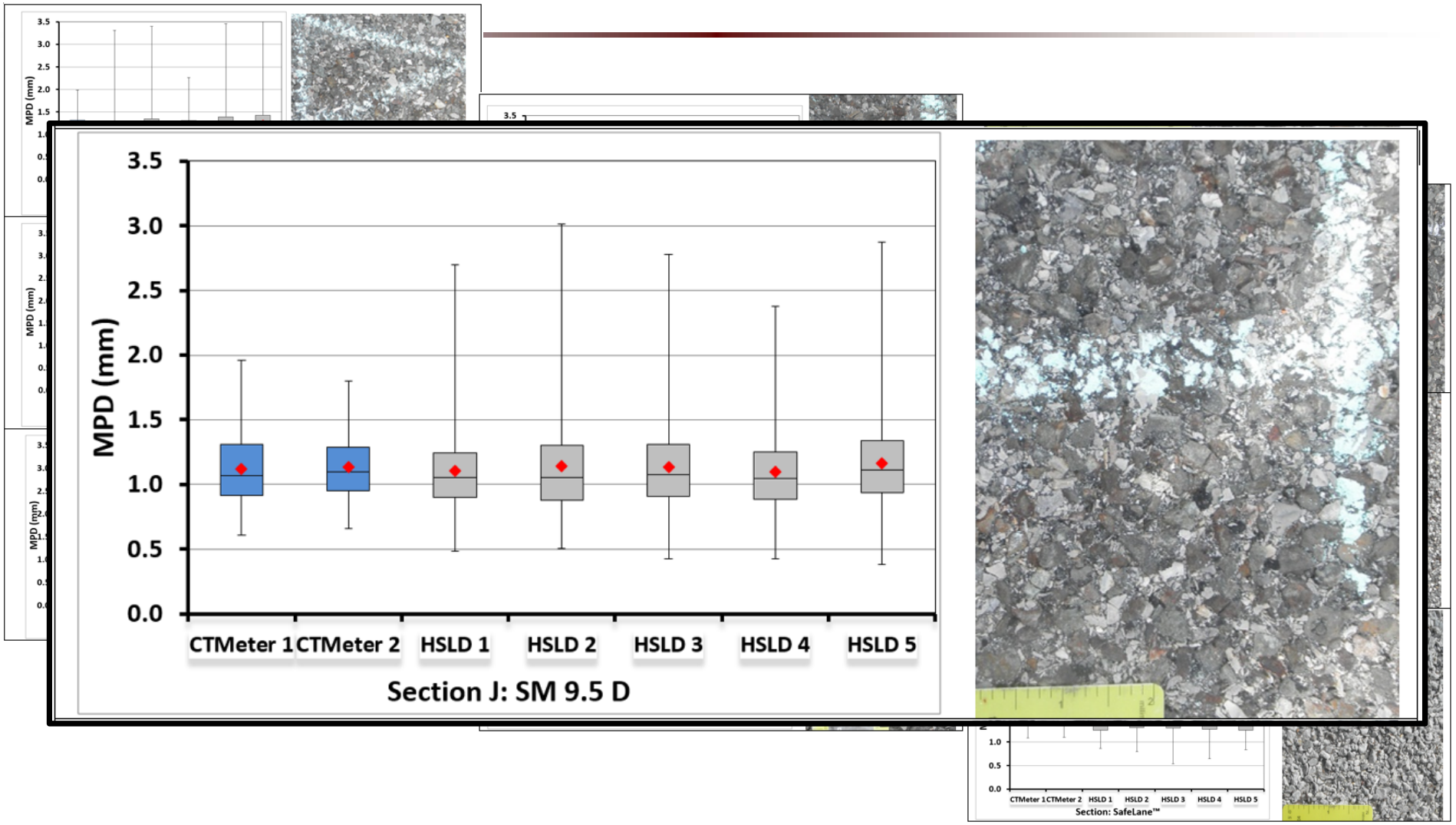
Results


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
MPD (mm)
Up to
14.8
Original Data (i.e. run 1)
Comercial Software (i.e. run 1)
Proposed Method (run 1)
Proposed Method (run 2)
Proposed Method (run 3)
Proposed Method (run 4)
Proposed Method (run 5)
Control
High Speed Laser Measurements
CTmeter Measurements

Results


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
MPD (mm)
Up to 14.8
Up to 11.1
Original Data (i.e. run 1)
Comercial Software (i.e. run 1)
Proposed Method (run 1)
Proposed Method (run 2)
Proposed Method (run 3)
Proposed Method (run 4)
Proposed Method (run 5)
Control
High Speed Laser Measurements
CTmeter Measurements

Results


MPD (mm)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
CTMeter 1
CTMeter 2
HSLD 1
HSLD 2
HSLD 3
HSLD 4
HSLD 5
Section J: SM 9.5 D
Section: SafeLane™

Conclusions

- An innovative and robust methodology for removing spikes from texture measurements gathered with an HSLD is proposed
  - ✓ → This is a significant step towards the development of standardized procedures that allow the use of these devices for texture investigation at network level.
- The test of the proposed methodology using a substantial amount of data collected over several and different pavement surfaces confirmed the ***reliability*** of the method on surfaces with different texture distributions, macrotexture depth, connectedness, porosity, etc.

Conclusions

- For all HSLD measurements, the proposed methodology was able to effectively remove (at least most of) the spikes from the texture profile on all the surfaces investigated.
- The validation of the method showed that the MPD results obtained with denoised dynamic measurements are comparable to MPD results from the control devices on all the pavement sections investigated.

Thank you