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

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Outline

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

Background

- **Today's technology allows collection and analysis of pavement macrotexture, not only with static, but also with dynamic methods, that can collect the pavement profile with significant precision even at traffic speed.**

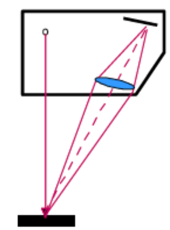
Background

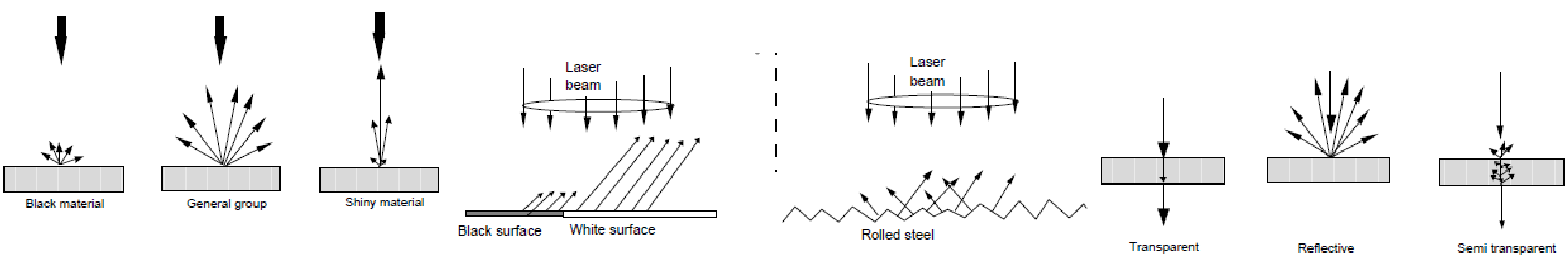
- A standardized procedure for texture measurements at network level is not yet available
- Studies show that besides the traditional low-pass filtering, slope suppression, and drop out correction; the calculus of MPD values must be free of spikes.

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

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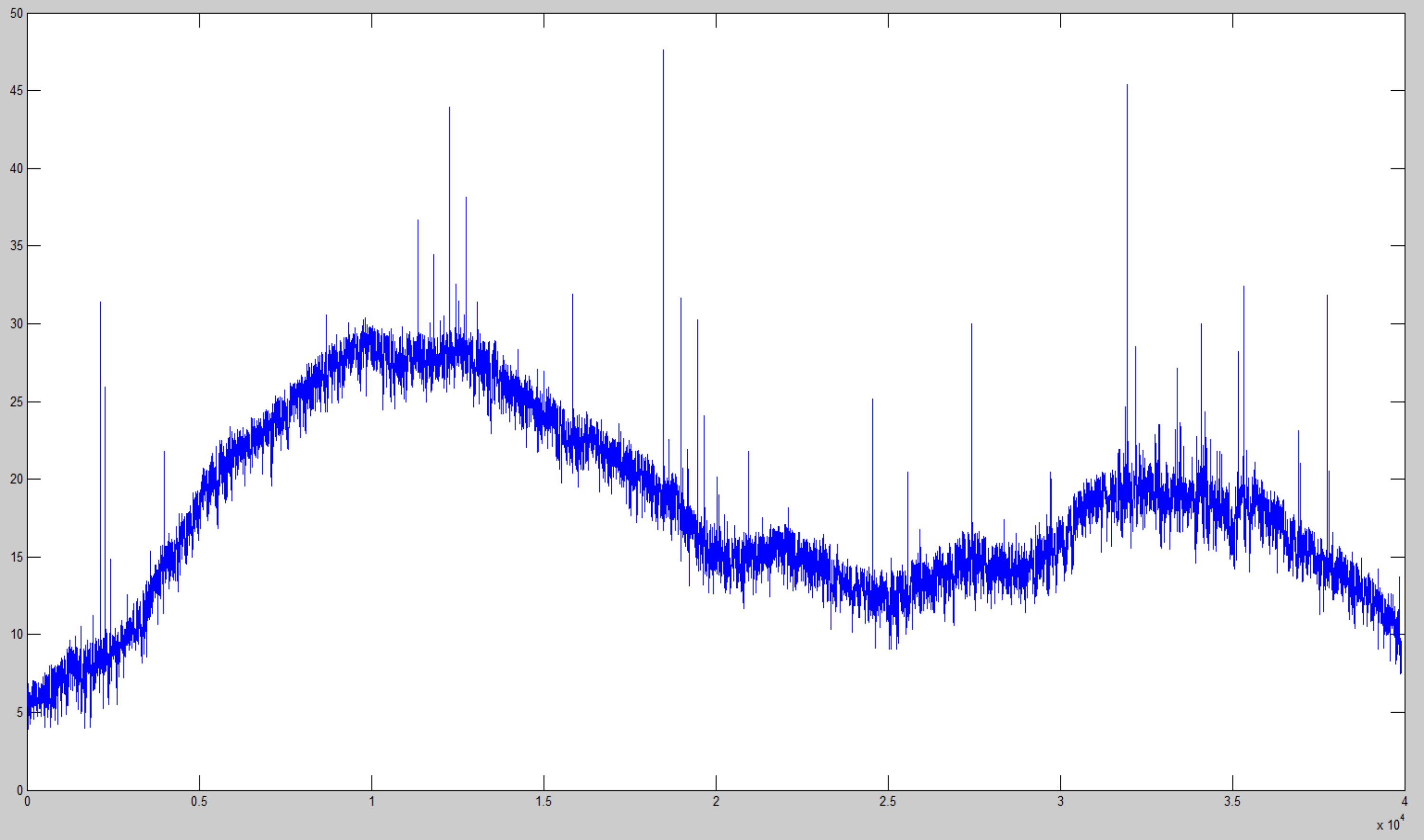
Problem Statement

- **All laser measurements have spikes**
- **They create biases on the texture measurements.**
- **→Need to remove those spikes in order to get good values for texture**

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

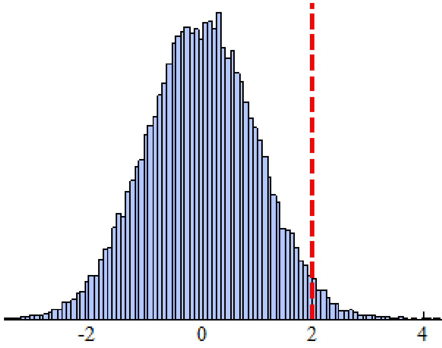
- **Methodology:**
  - ✓ **First, determines the <u>distribution</u> of texture measurements, and**
  - ✓ **Second, determines which measurements are outliers and therefore spikes (determine a <u>threshold</u>)**

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

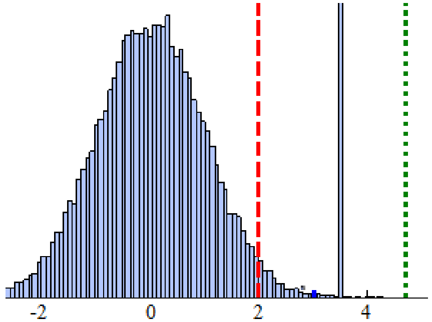
- **Methodology (threshold):**
  - ✓ **Normal distribution with a fixed 2 or 3 sigma threshold to define outliers?**
    - **2 sigma (which approximately covers 95 % of the distribution) or 3 sigma (about 99 %).**
    - **For example, 20 m pavement section, data every 0.5 mm → 40,000 measurements. <u>2 sigma threshold</u> → on average, <u>2,000</u> of the collected measurements will be identified as spikes. Even with using <u>3 sigma</u> as a threshold, <u>400</u> measurements will be identified.**



    - **They fail to address one crucial aspect of high speed texture measurement – <u>the large amount of data collected</u>.**

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 <u>wrongly identifying outliers</u>, it will miss detecting outliers that are just under the Bonferroni threshold.**



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

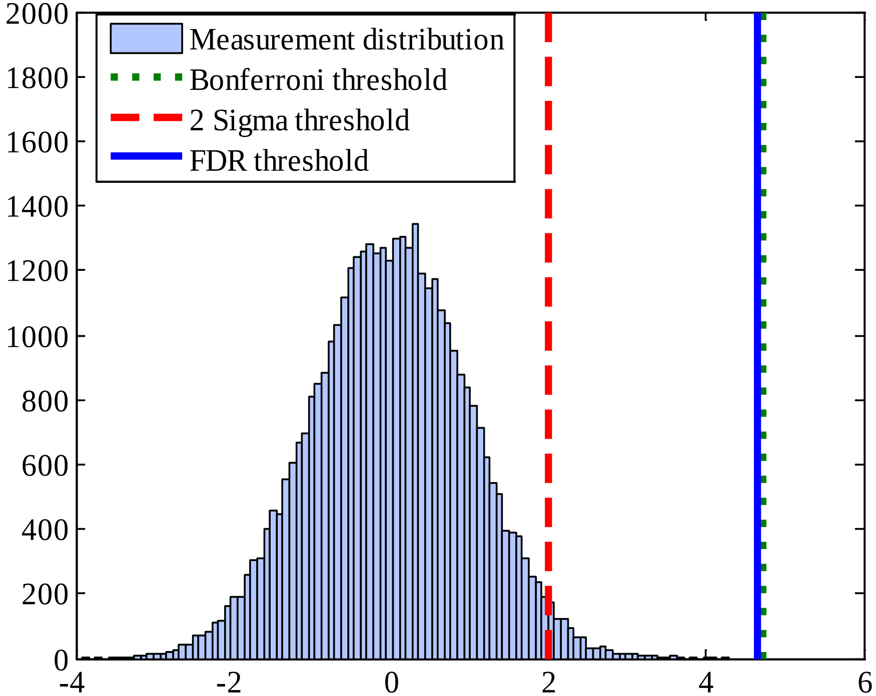
Research approach

- **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 $p_1 \leq \ldots \leq p_i \leq \ldots \leq p_n$
    - 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: $p_i \leq \frac{i}{n} q$
    - Spikes are identified as all measurements whose p-value is $\leq p_k$

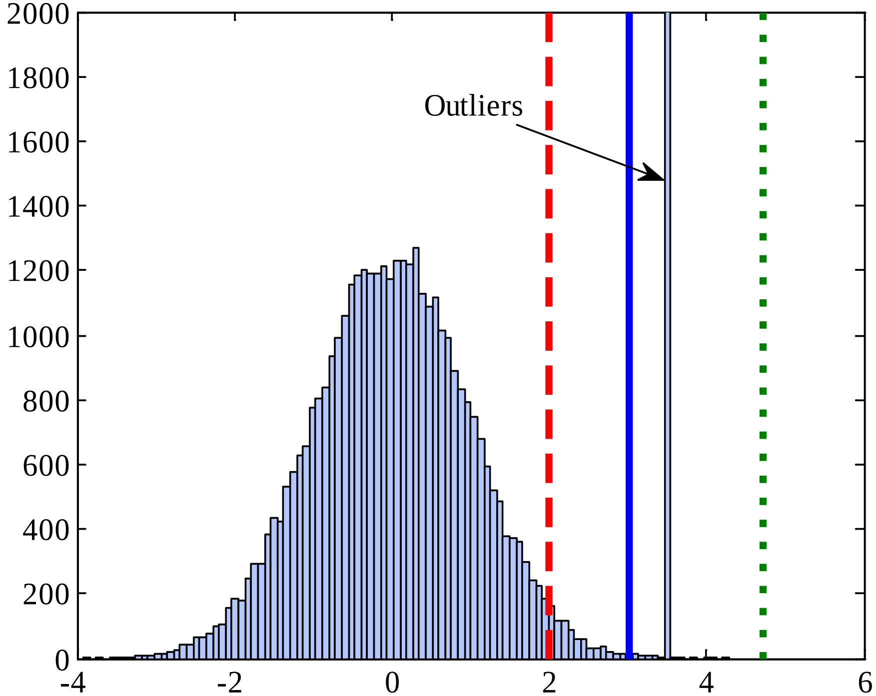
$$FDR \leq \frac{n_0}{n} q \leq q$$

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:**

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

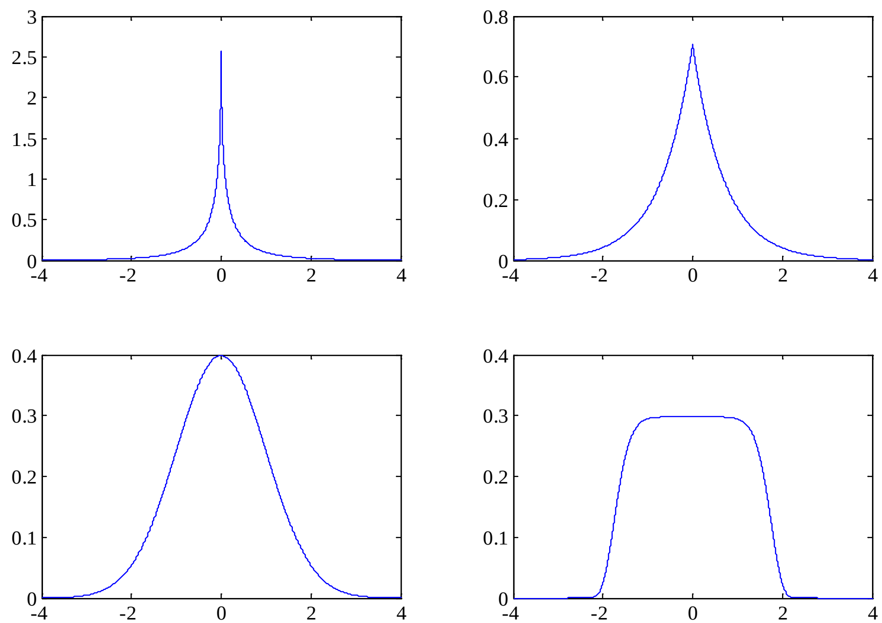
β is a shape parameter (positive),

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

μ is a location parameter (average).

β = 0.5

β = 1
(Laplace distribution)

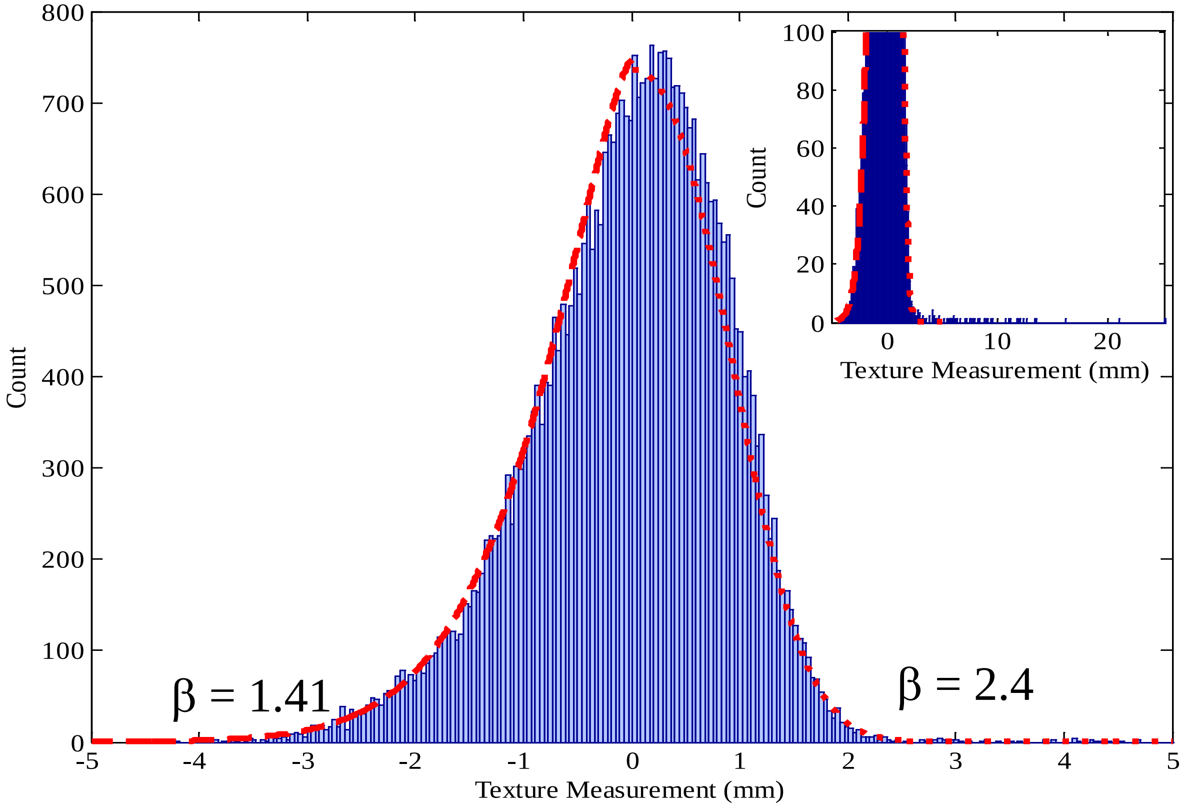


β = 2
(normal distribution)

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

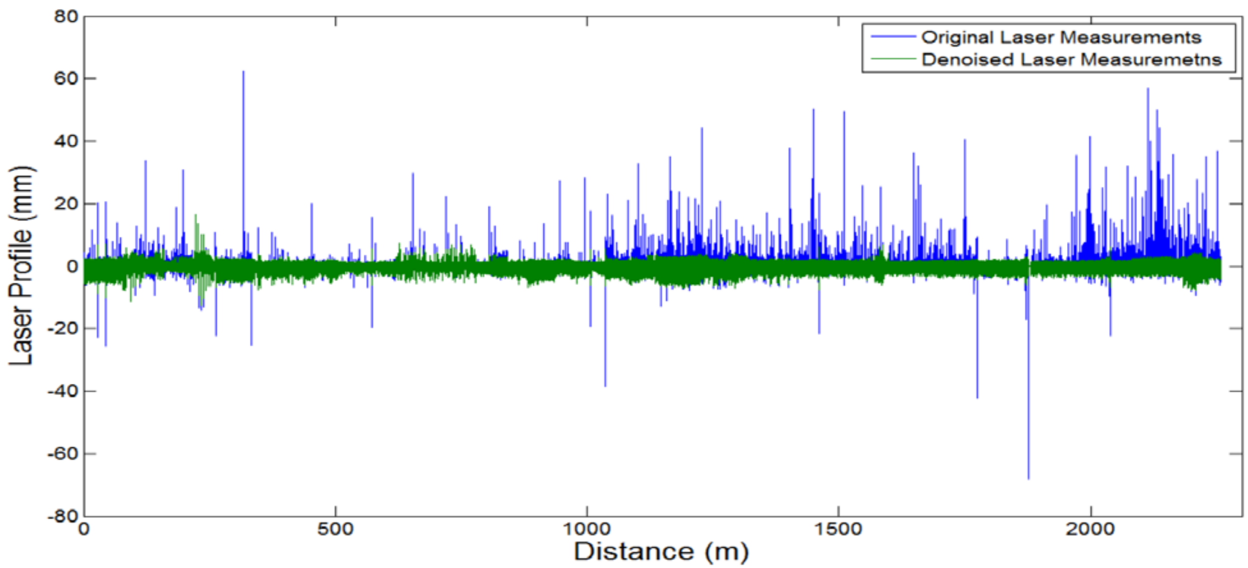
Results

- Ten <u>randomly</u> 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.

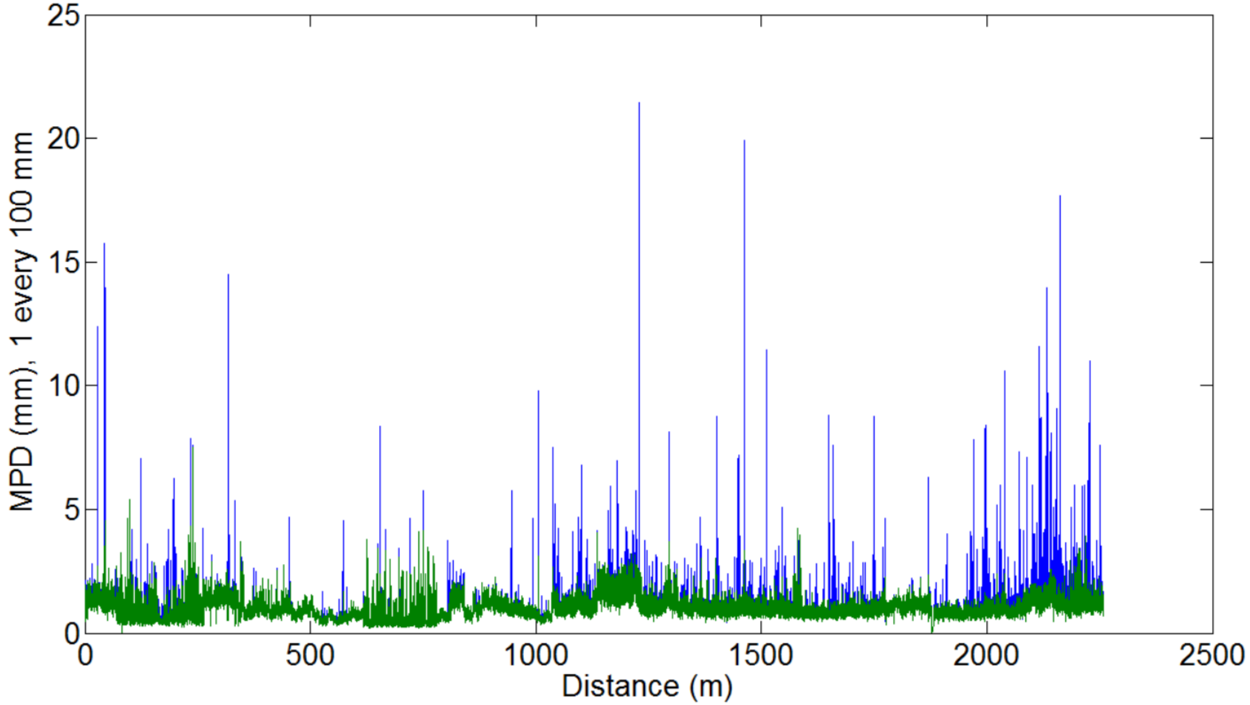
Profile Measurements from the HSLD, with and without Spikes (i.e. run 3)



Results

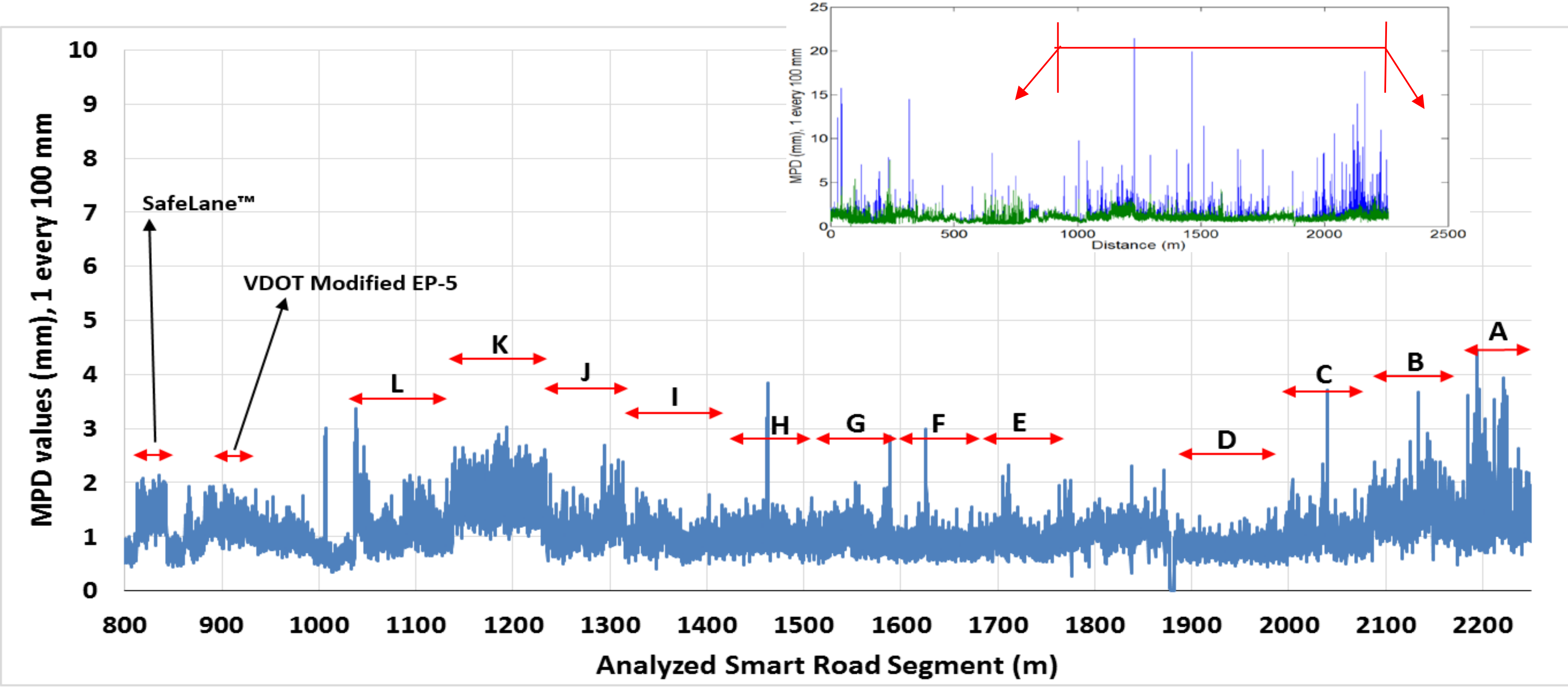
- The MPD calculations using the ASTM E1845-09
- MPD measurements (one value every 100 mm)

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)



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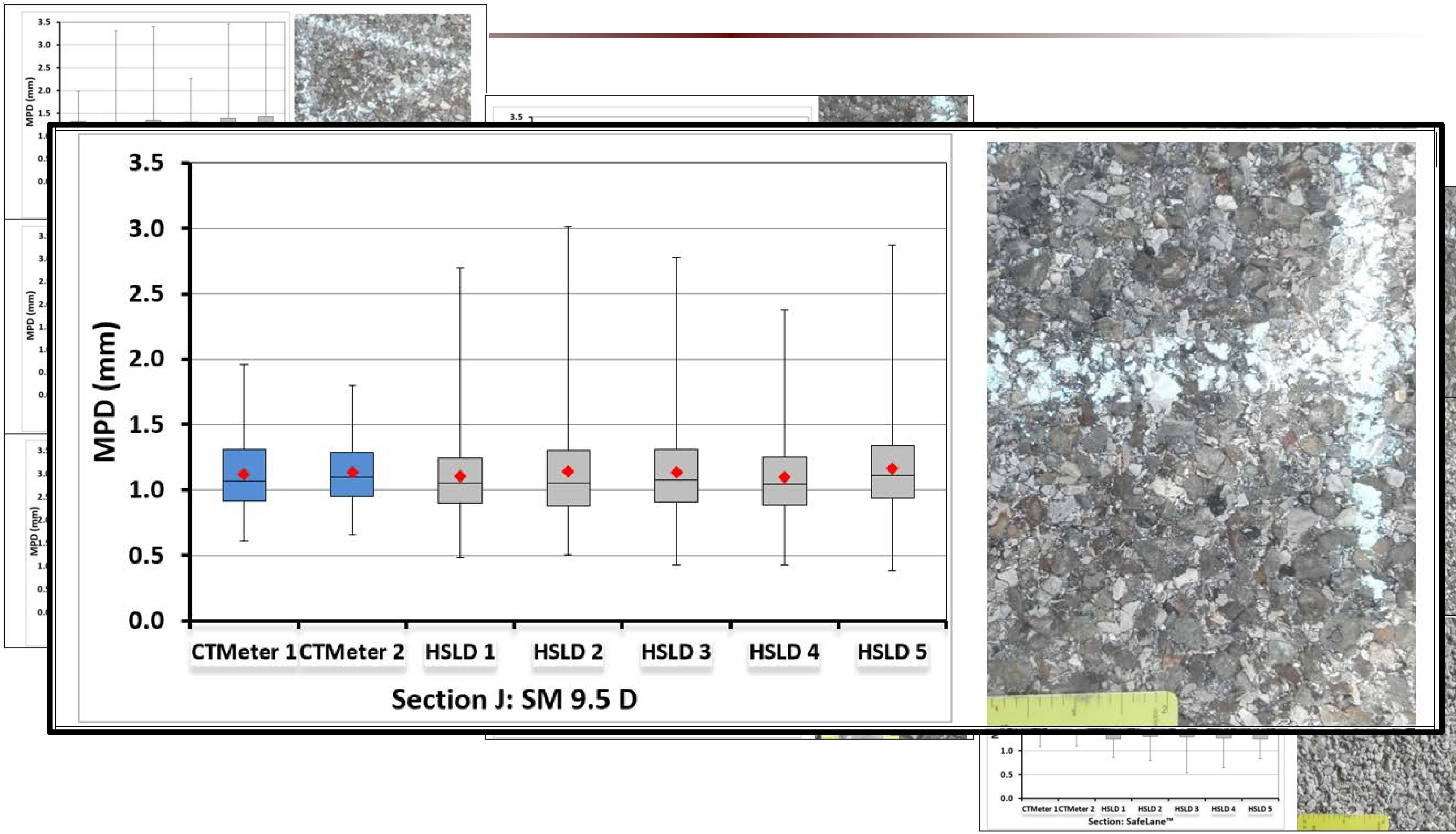
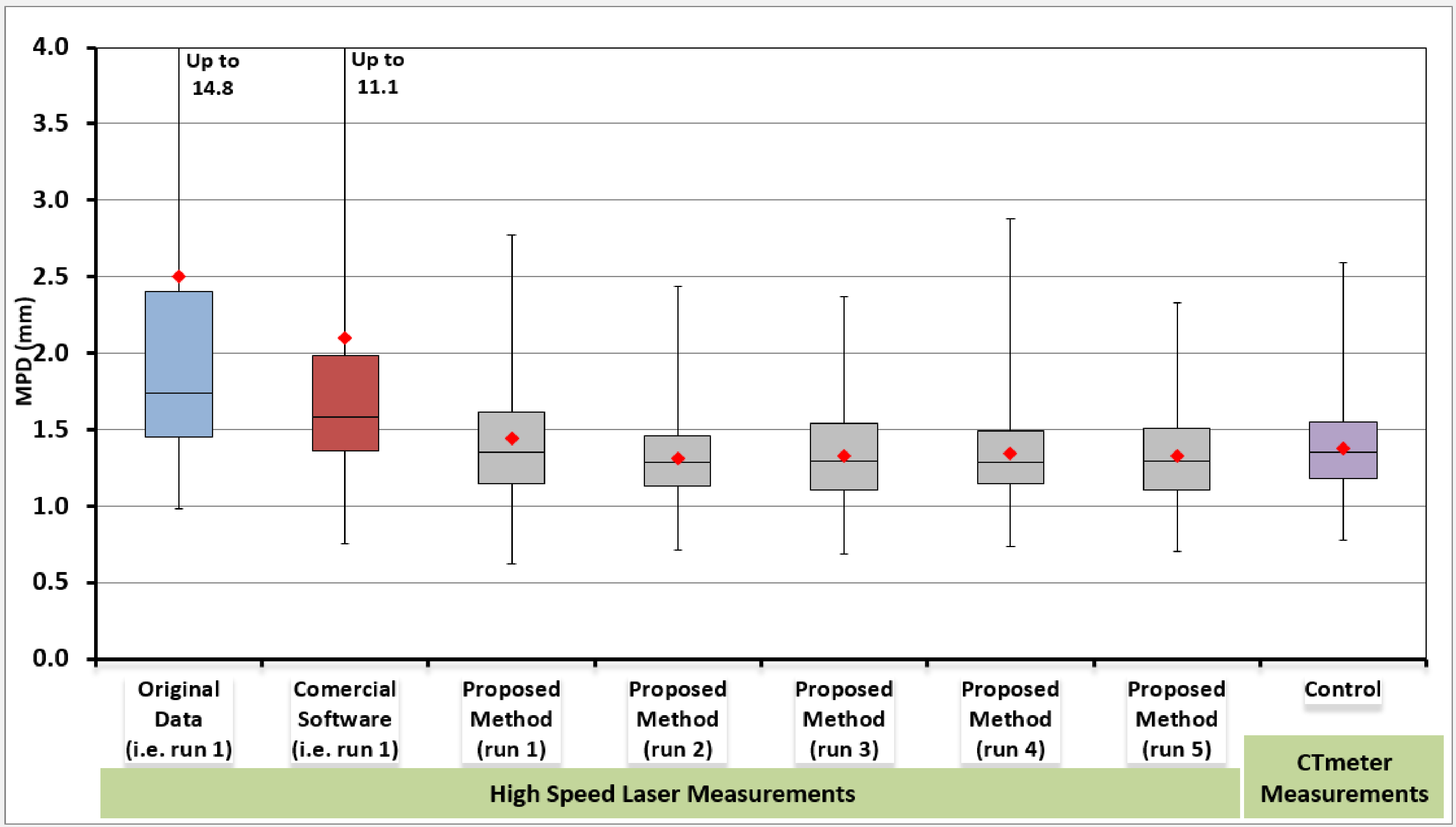
Results


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

Validation



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

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