Friction Studies-From Passive to Intelligent Tires

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CenTiRe Vision

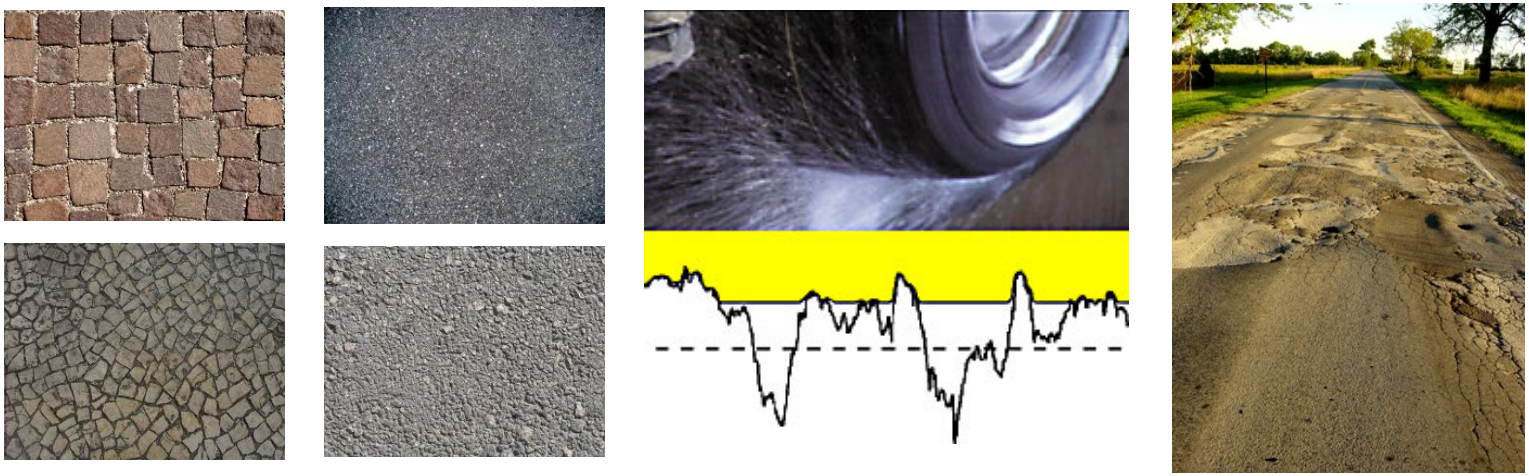
- The Center for Tire Research will provide the forum for industry/university cooperative research for the further development, validation, and industrial implementation of the emerging technologies of tire materials, manufacturing, modeling, and testing.

Relevant Projects

- Multi-Scale Modeling of Tire-Road Contact and Adhesion
- Tire-Soil Interaction Model
- Pneumatic Tire Performance on Ice
- Macro Road Surface Profiling
- A Portable Low-Cost System for High-Speed High-Precision Surface Profiling
- High-Precision Tire Modeling and Analysis for Tire-Road Noise Prediction
- Estimating Tire-Road Friction from Probe Vehicles

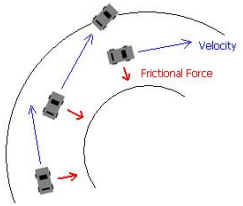
Multiscale Modeling

- To better understand tire and vehicle performance, a better understanding of tire-road contact mechanics is needed
- Accurate road profiles -> extract characteristic properties (e.g., friction, roughness)
- Build a comprehensive, multi-scale database of Pavement Surface Characteristics and friction
- Tire-road contact modeling using Wavelet and Fractal based approach



Background/Introduction

- A major problem in highway safety and traffic engineering is to understand the mechanisms of friction between the tire and the road.



- Pavement surface texture significantly contributes to tire-pavement friction.
- Several researchers have claimed that road profiles are fractal, and that this fractality is related to the friction properties of the road.
- The objective here is to present texture properties and contact mechanics that can predict tire-pavement friction.

Rubber Road Contact

In order to be able to estimate friction between rubber and a rough surface, we need to:

- Measure the surface profile (possible through using the Nanovea optical profilometer)
- Characterize the surface
- Characterize the tread compound
- Calculate the real area of contact
- Estimate cold friction
- Include the effect of flash temperature

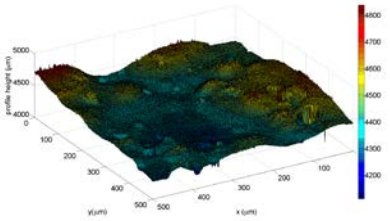
Estimated Friction

$$C(q)=\frac{1}{(2\pi)^2}\int d^2x\,\langle h(\mathbf{x})h(\mathbf{0})\rangle e^{-i\mathbf{q}\cdot\mathbf{x}}$$

Power Spectral Density of profile height

$$C(q)\approx k(q/q_0)^{-2(H+1)}$$

Simplified version for self-affine surfaces

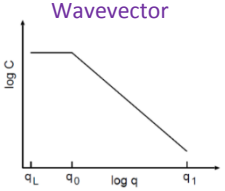


$$P(q)=\frac{2}{\pi}\int_0^\infty dx\,\frac{\sin x}{x}\exp[-x^2G(q)]$$

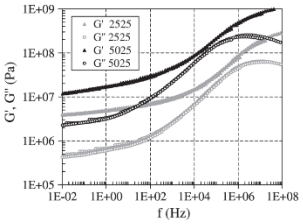
$$G(q)=\frac{1}{16\pi}(q_0h_0)^2H\int_1^{q/q_0}d\zeta\,\zeta^{-2H+1}\times\int d\phi\left|\frac{E(q_0\zeta v\cos\phi)}{(1-\nu^2)\sigma_0}\right|^2.$$

The stress probability distribution in the contact area on each length scale

PSD vs. Wavevector

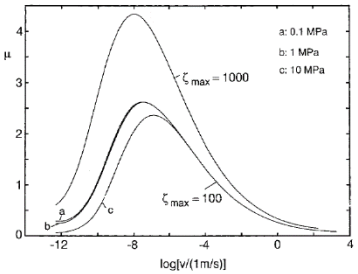


CB-filled SBR



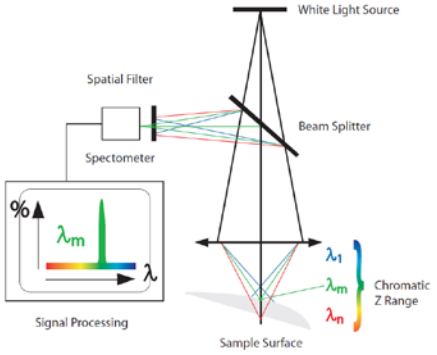
$$\mu\approx\frac{1}{4\pi}(q_0h_0)^2H\int_1^{q_1/q_0}d\zeta\,\zeta^{-2H+1}P(q_0\zeta)\times\int d\phi\cos\phi\,\mathrm{Im}\frac{E(\zeta q_0v\cos\phi)}{(1-\nu^2)\sigma_0}$$

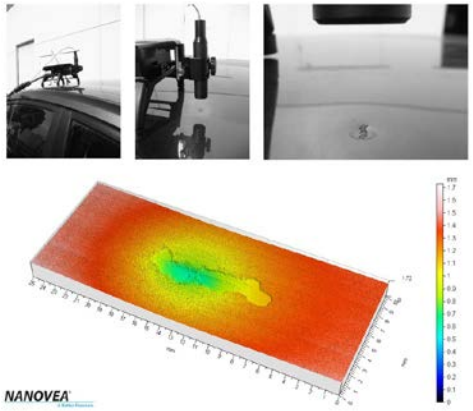
Kinetic coefficient of friction



Nanovea JR25

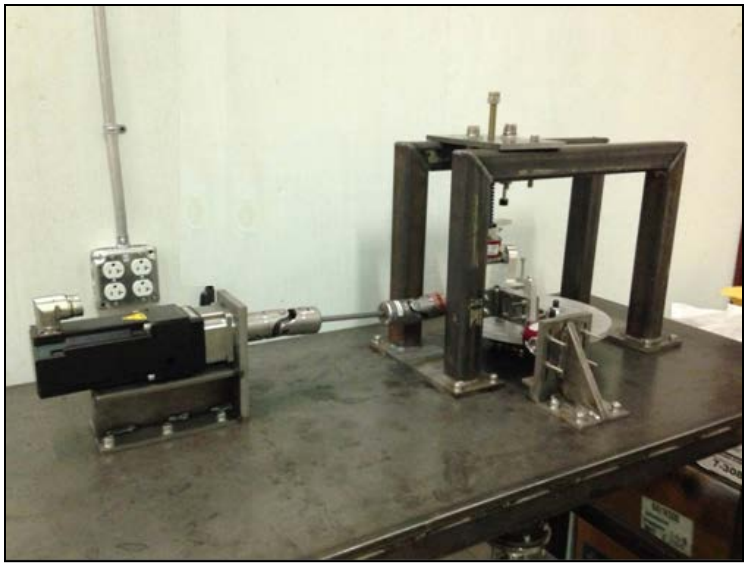
- Designed with leading edge optical pens using superior white light axial chromatism.
- Excellent vertical and spatial resolution.
- Add-on features:
  - Contour measurement
  - Fracture surface measurements
  - Surface wear subtraction
  - Adhesion surface topography

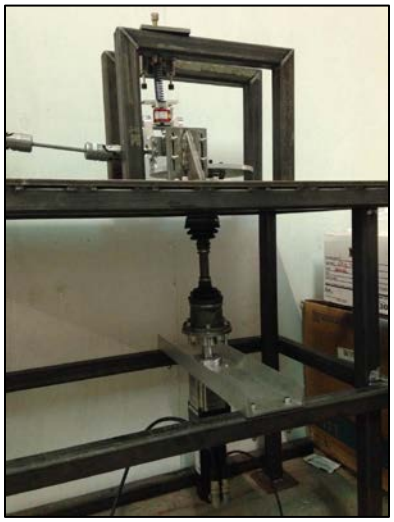


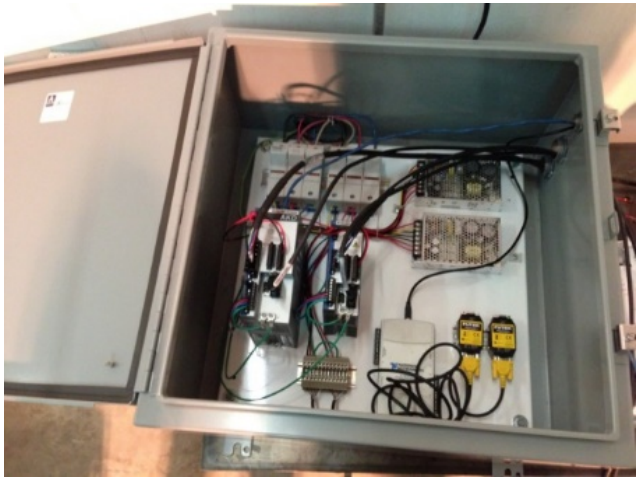


Friction Tester

- **Outdoor testing:**
  - Weather conditions.
  - Time -- Money -- Human resources
- **Indoor Testing:**
  - Reduced cost
  - Controlled laboratory environment
  - Improved data accuracy and reproducibility
  - Ease of data accessability and processing

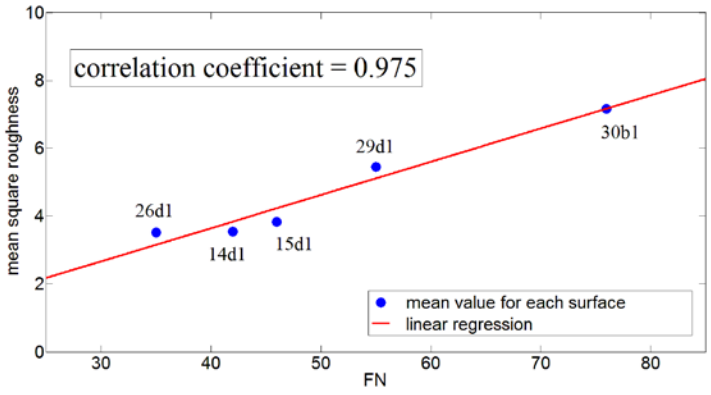


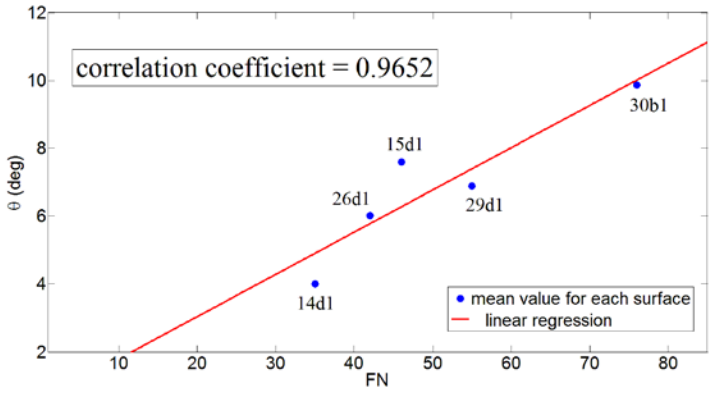




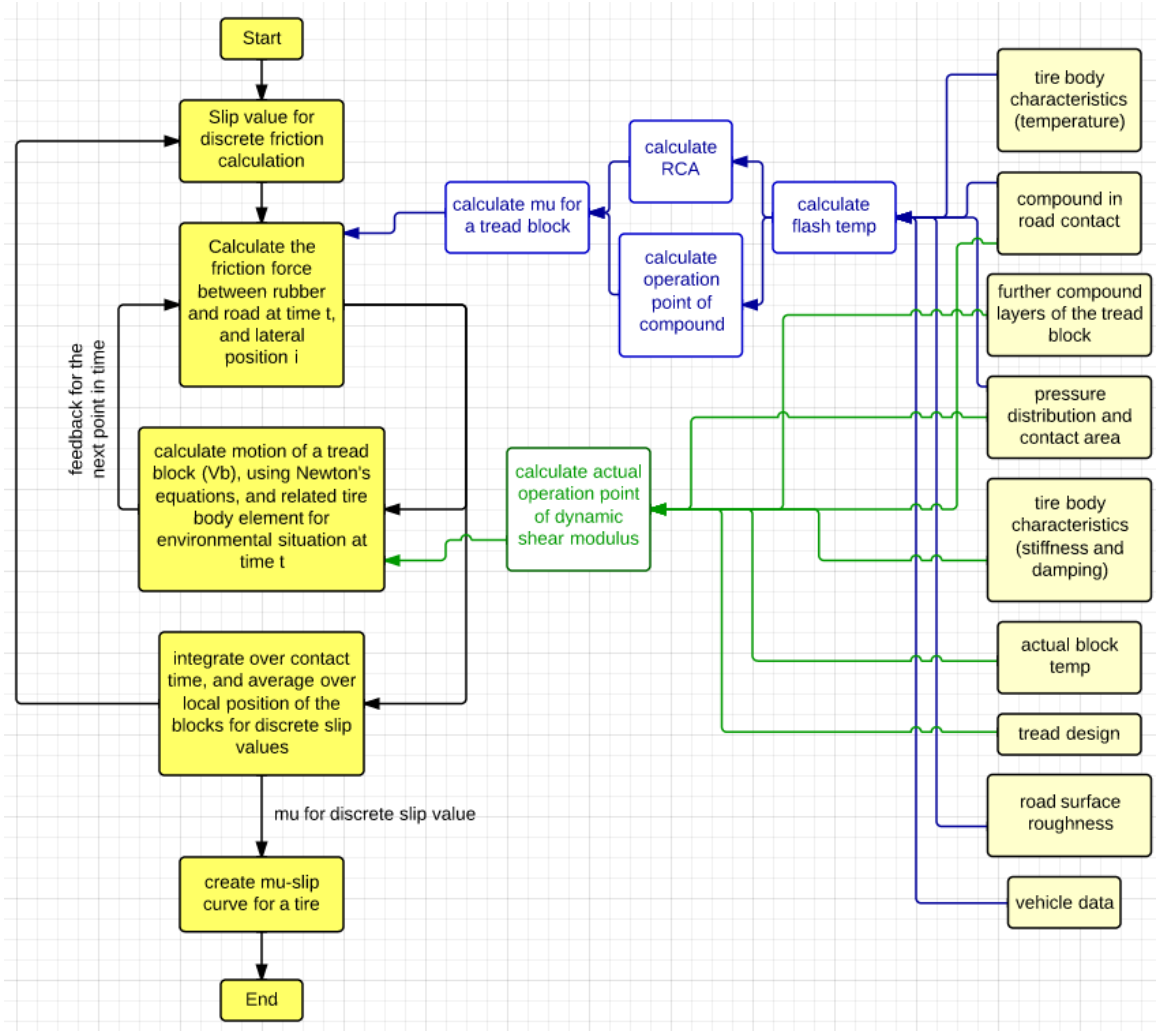
Road Profile Characterization

Profile		Mean Square Roughness	Power Spectral Density
B0	0.48	0.0511	0.0502
B90	0.39	0.0405	0.0398
C180	0.35	0.0374	0.0366

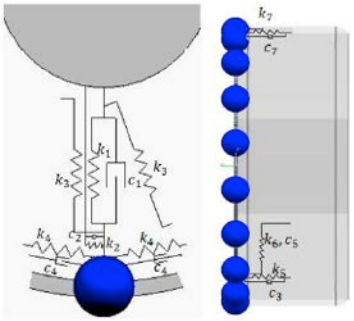




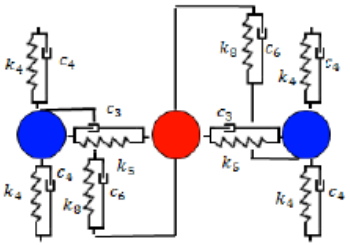
μ-Slip Curve for Tires



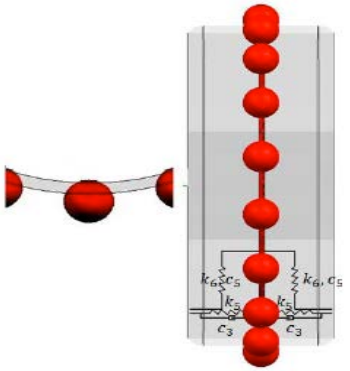
Tire-Soil MBD Model



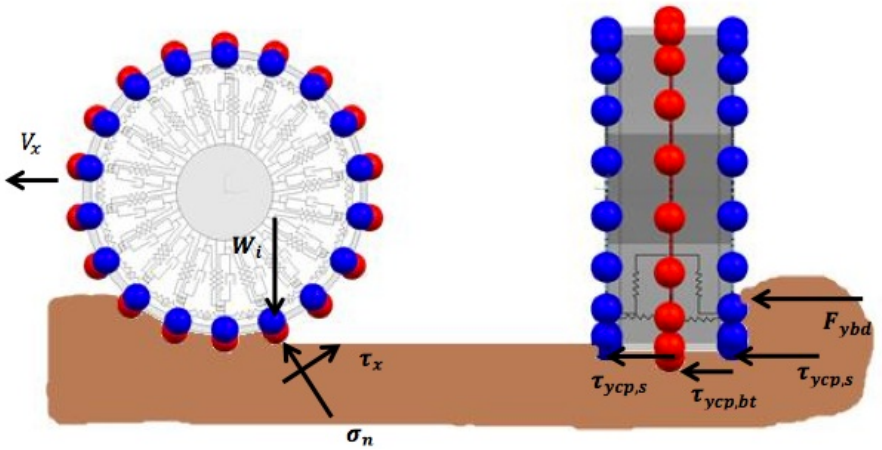
Side wall diagram



Circumfrential plane



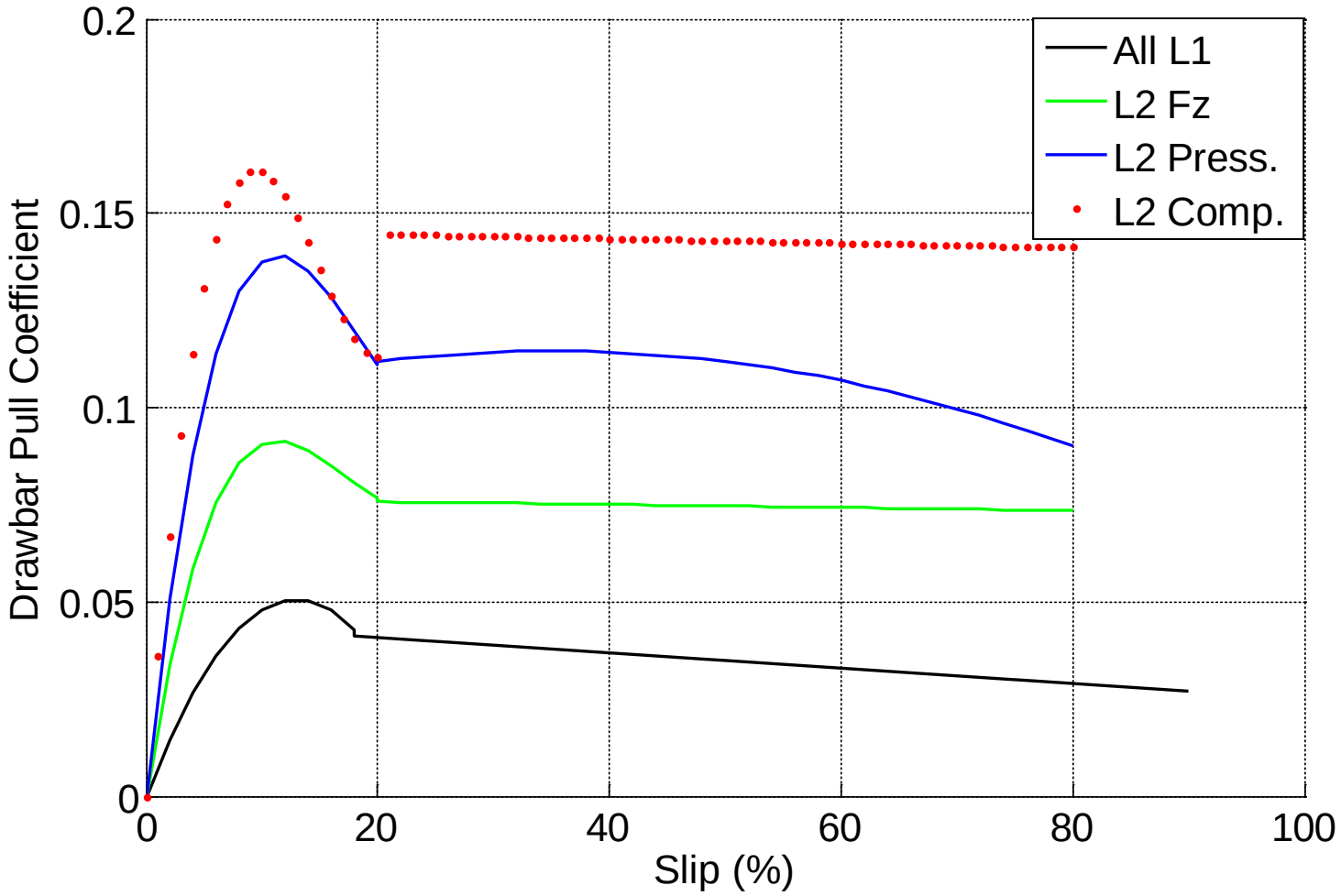
Tread and belt diagram



Terramechanics Rig

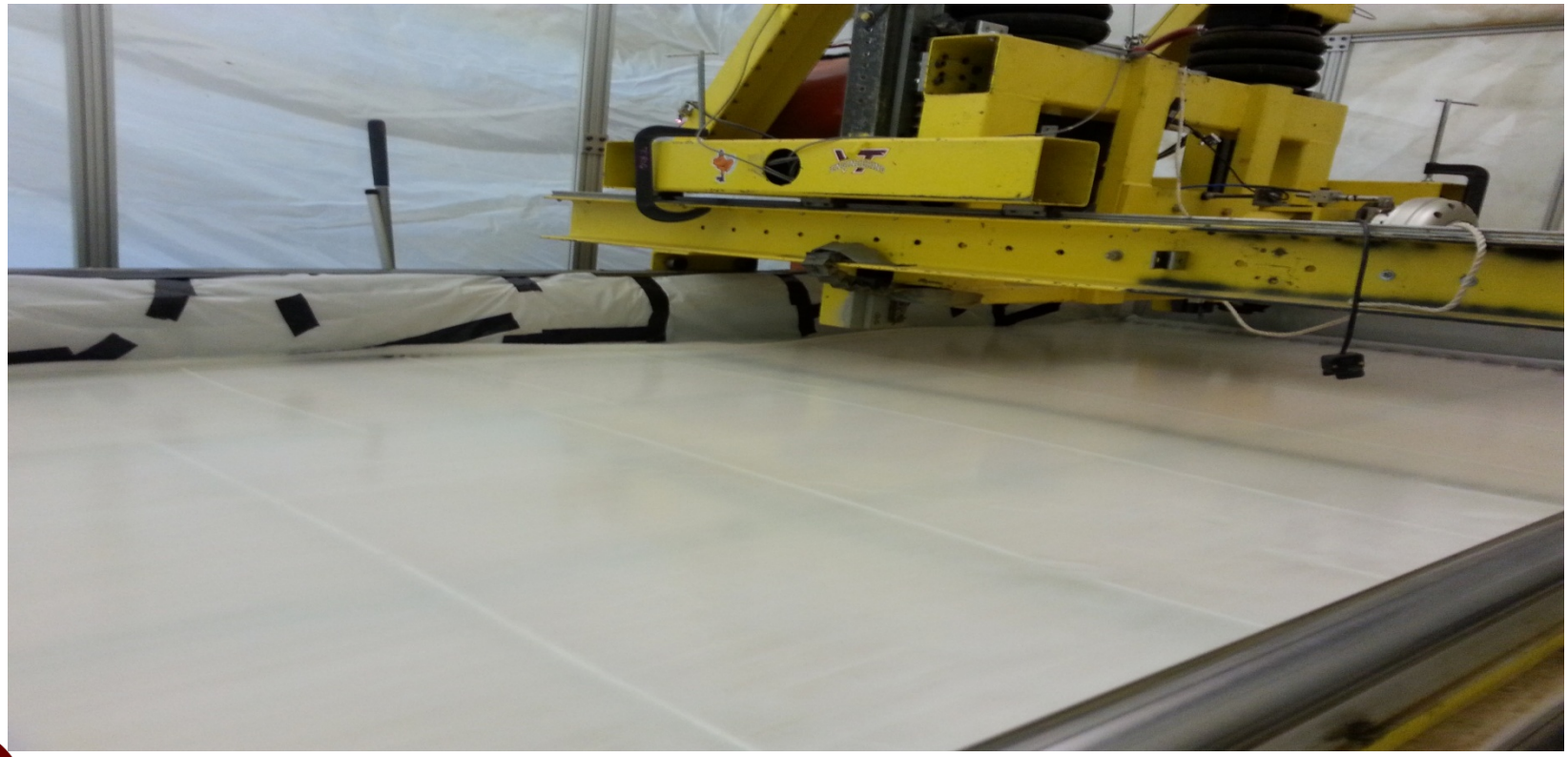
Test Tire: Michelin LTX A/T2 235/85/R16

DOE – Individual Parameter Change



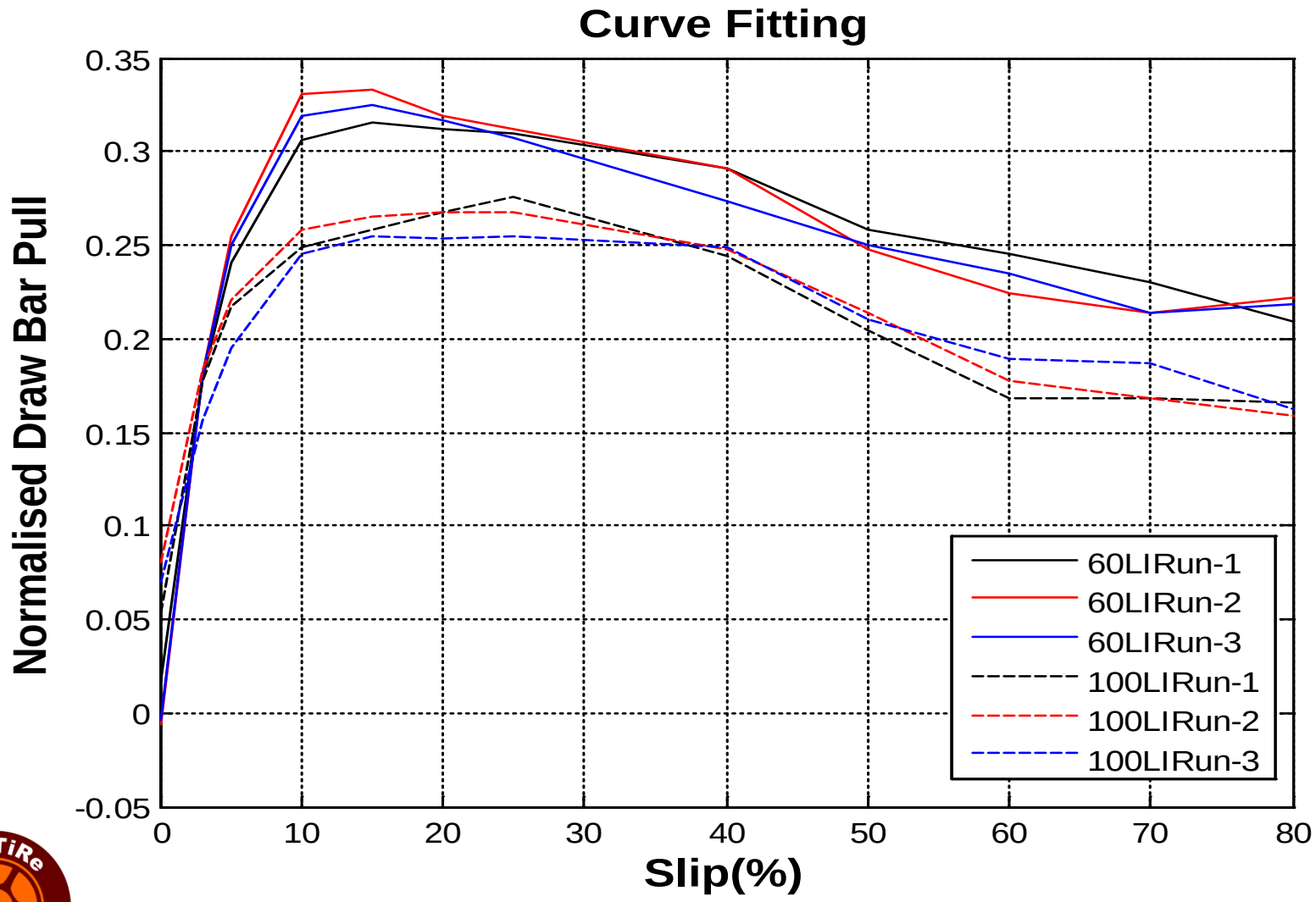
Ice Project

- 2 inches thickness of ice
- Ambient Temperature= 15-17^{0}C

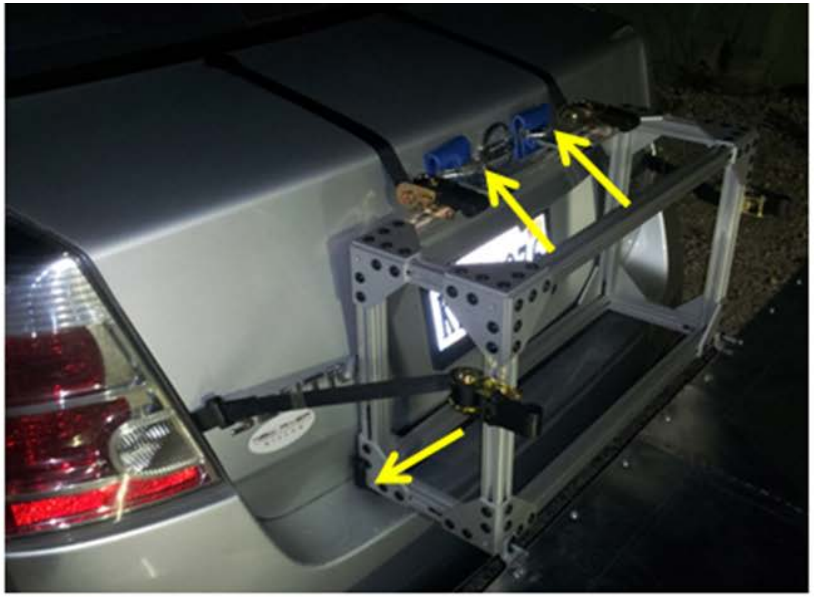


Video

Results


Curve Fitting
Normalised Draw Bar Pull
Slip(%)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
10
20
30
40
50
60
70
80
60LIRun-1
60LIRun-2
60LIRun-3
100LIRun-1
100LIRun-2
100LIRun-3

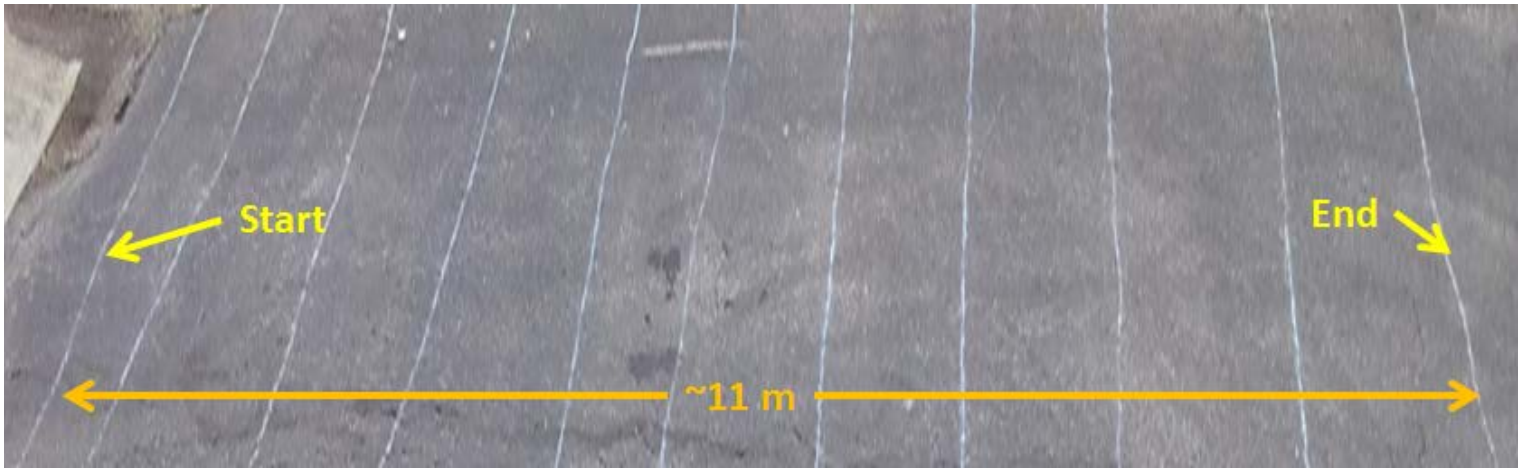
Macro Road Profilometer Prototype System



Padded surface contacts

Four anchor points

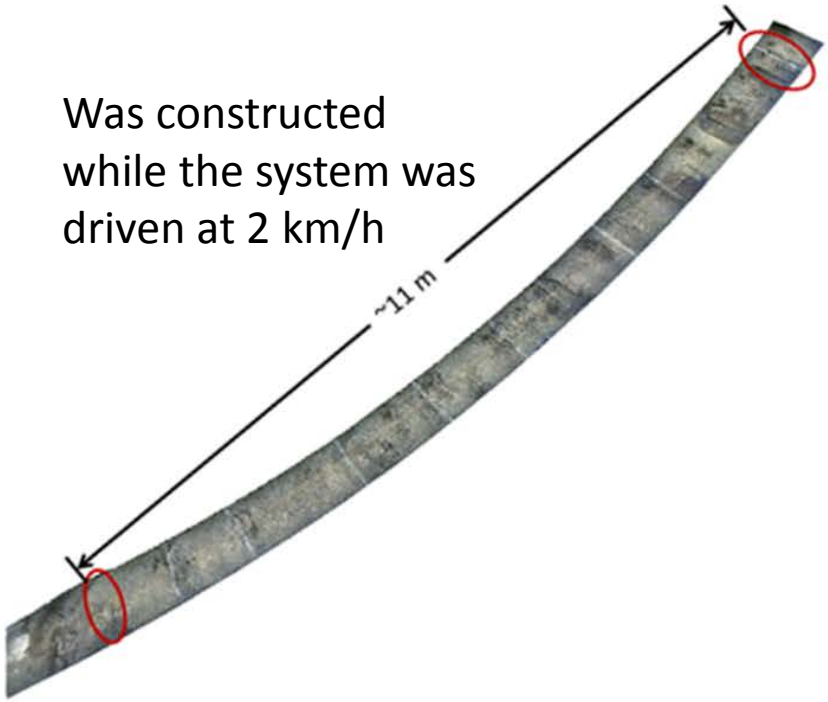
Experimental Setup



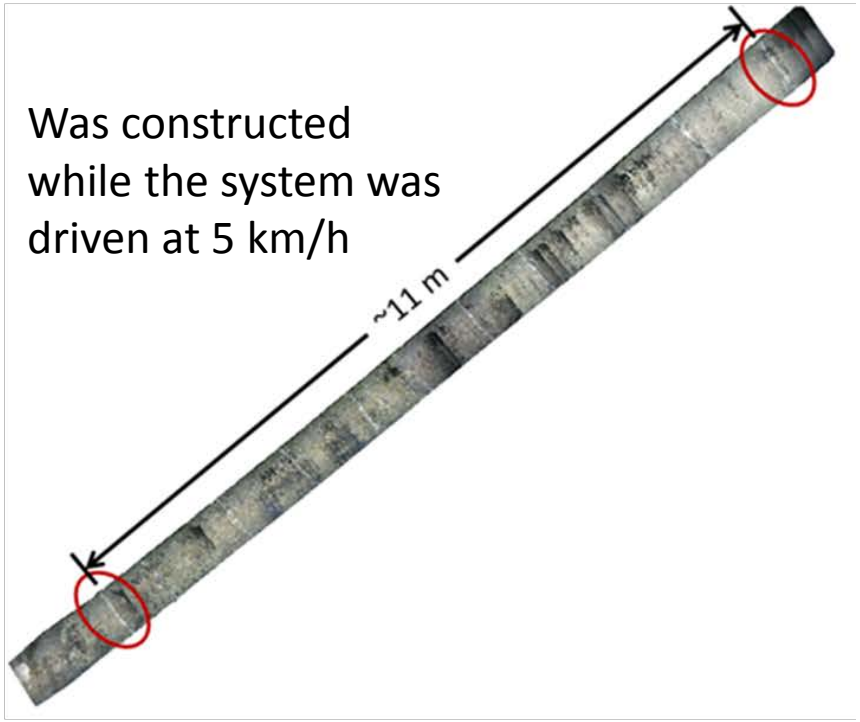
- Identify scan matching algorithm's ability to assemble road profiles
  - Image features are trackable
  - Depth measurements are preserved

Road Profiling Results

Was constructed while the system was driven at 2 km/h



Was constructed while the system was driven at 5 km/h

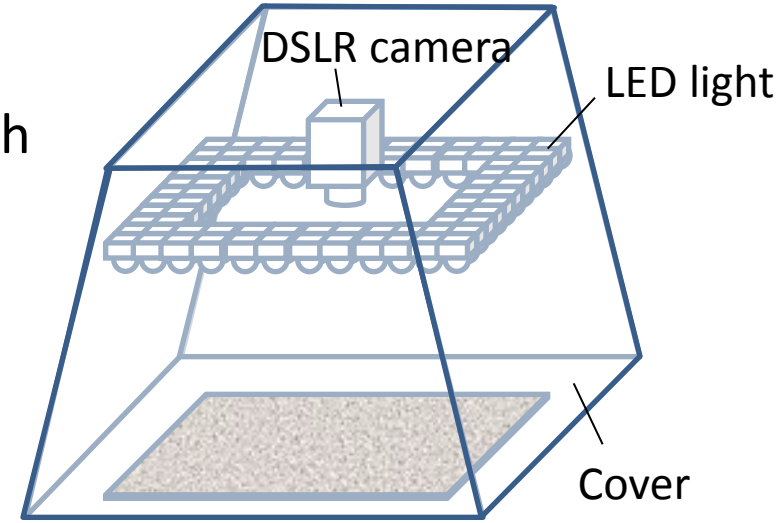


— Endpoints

Micro Road Profiling System

Core procedures:

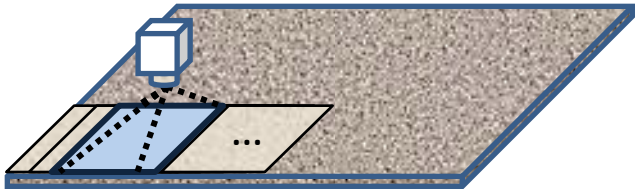
- Images taken with single LED on each time
- 3D surface reconstruction from images via Shape from Shading (SfS)
- Scan matching for large area measurements



Proposed conceptual system [1]

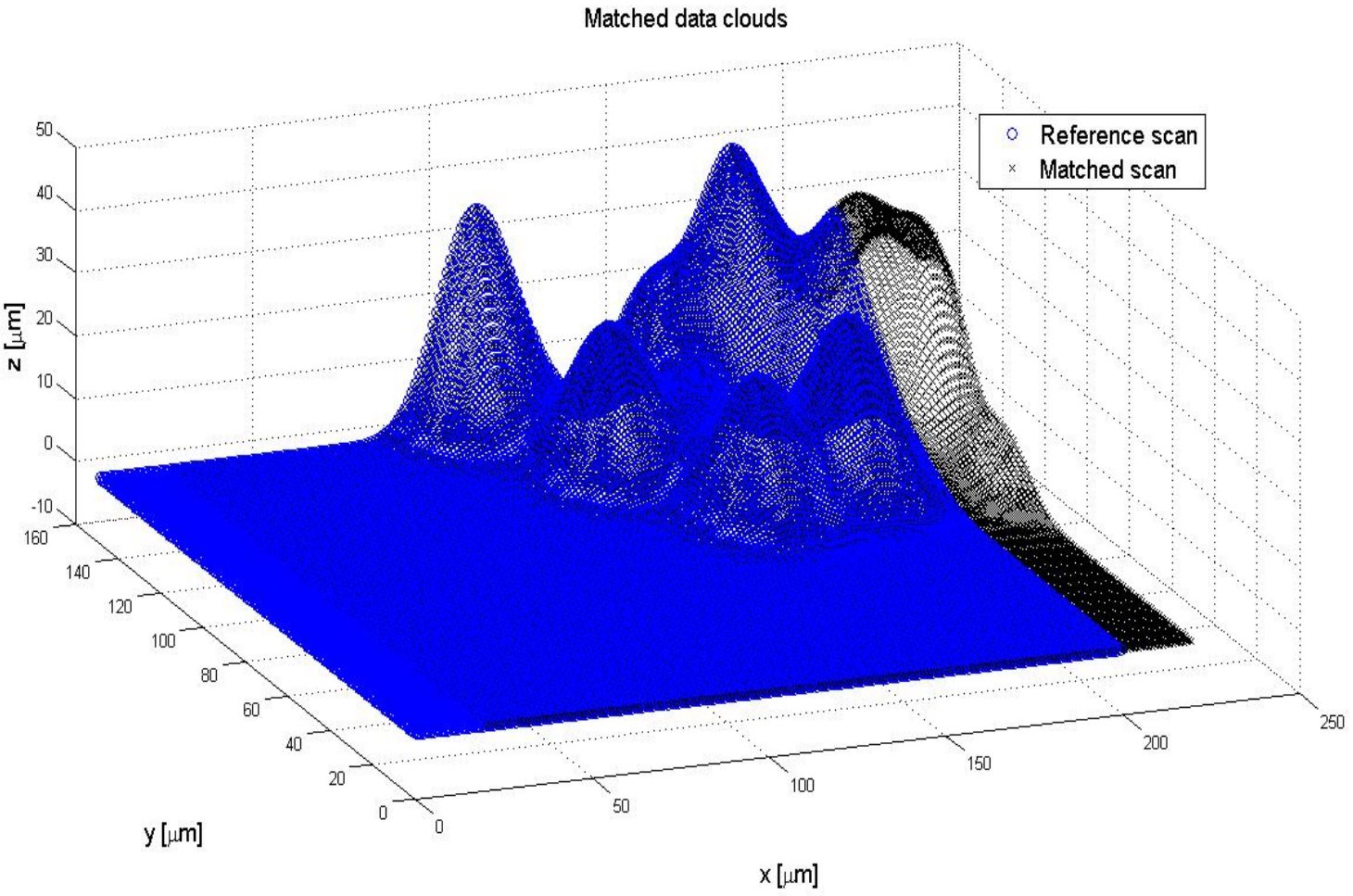
Special features:

- Fast data acquisition due to area scan
- Compact and mobile

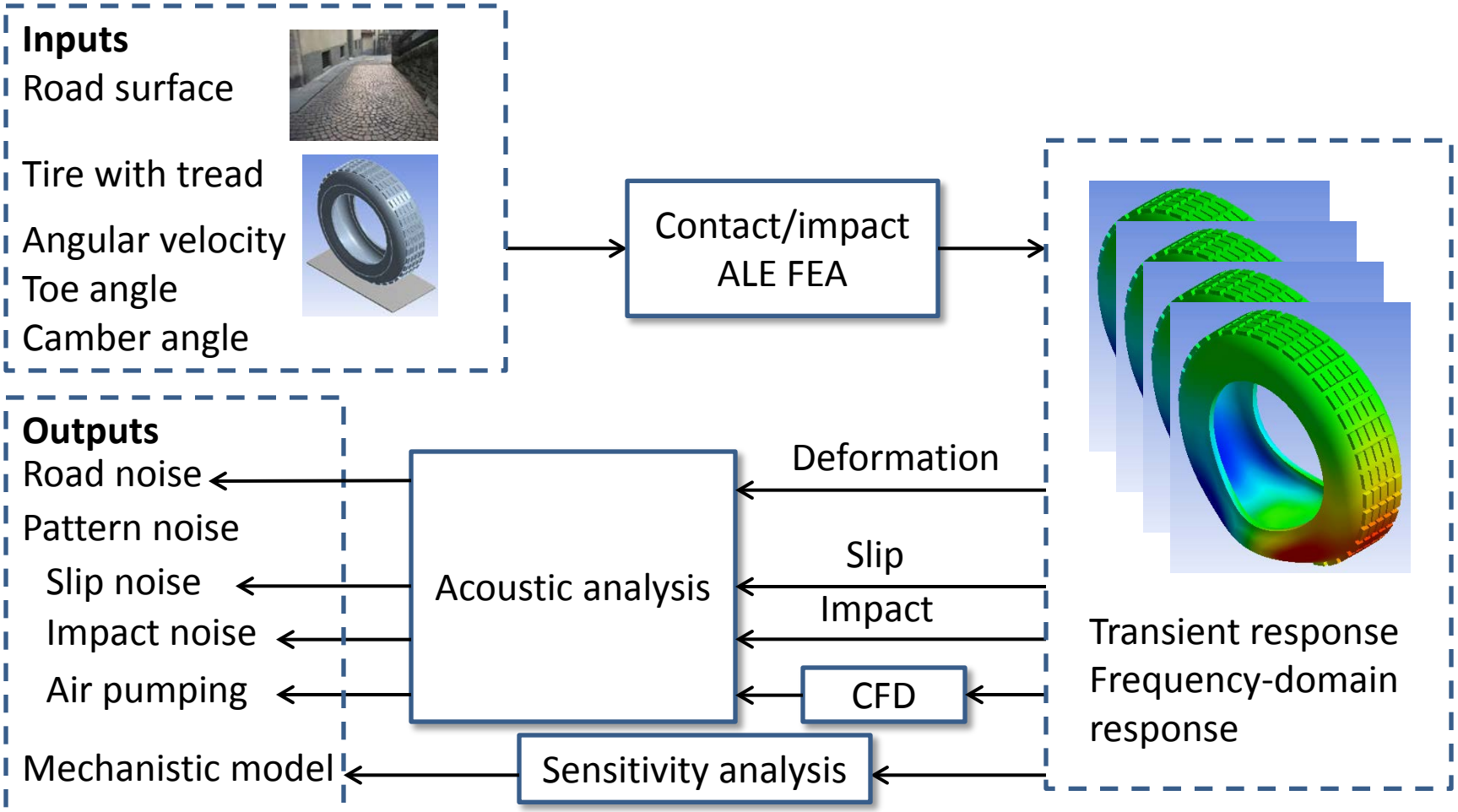


Scan matching

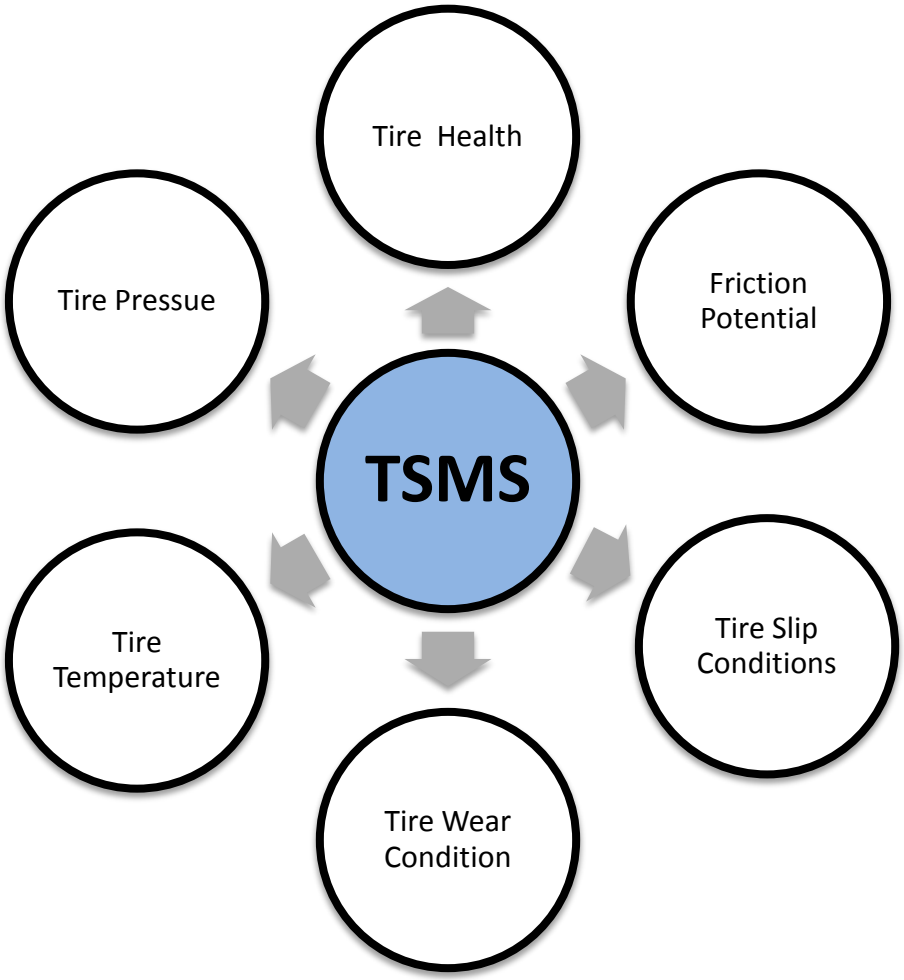
Results


Matched data clouds
Reference scan
Matched scan
z [μm]
y [μm]
x [μm]
50
40
30
20
10
0
-10
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250

Noise Modeling

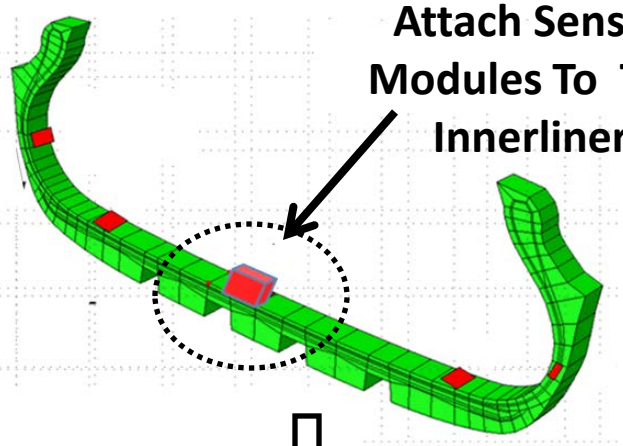


Tire State Measurement System-TSMS



Tire State Measurement System

Methodology



Robust And Prompt Information About The Contact Dynamics, Health, Temp, Pressure, ..

Eliminating Uncertainty-adding Procedures

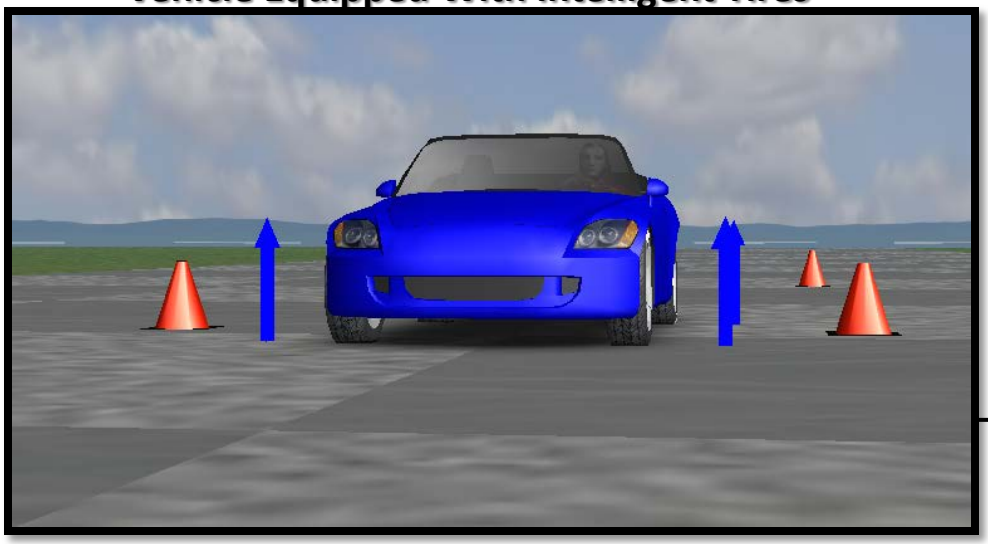
Add "Intelligence" To The Modern Day Passive Tire

Intelligent Tire System

The Tire of The Future

"Tire- In -The Loop (TIL) System"

Vehicle Equipped With Intelligent Tires



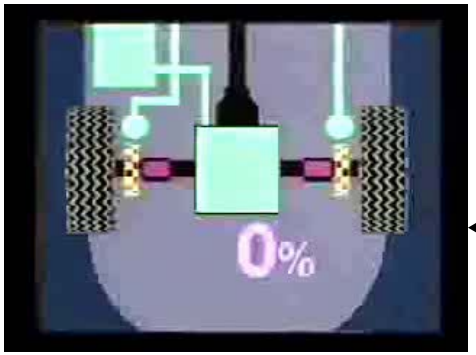
Feedback From The Tire

Low Grip Driver Assist System

(Drivers can adjust their driving style)

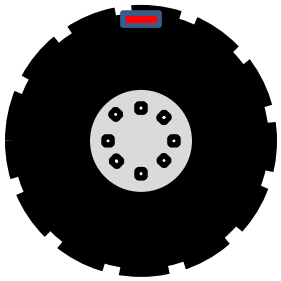
On-board Vehicle Controller

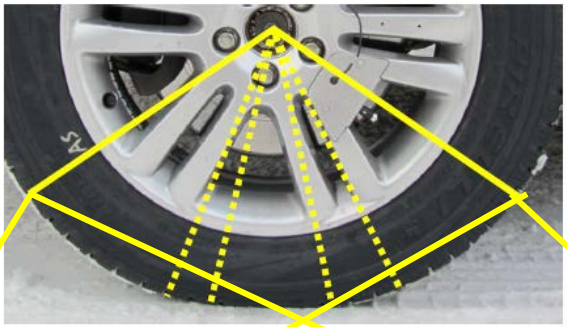
(Improve the performance of current control systems like ABS/VSC)

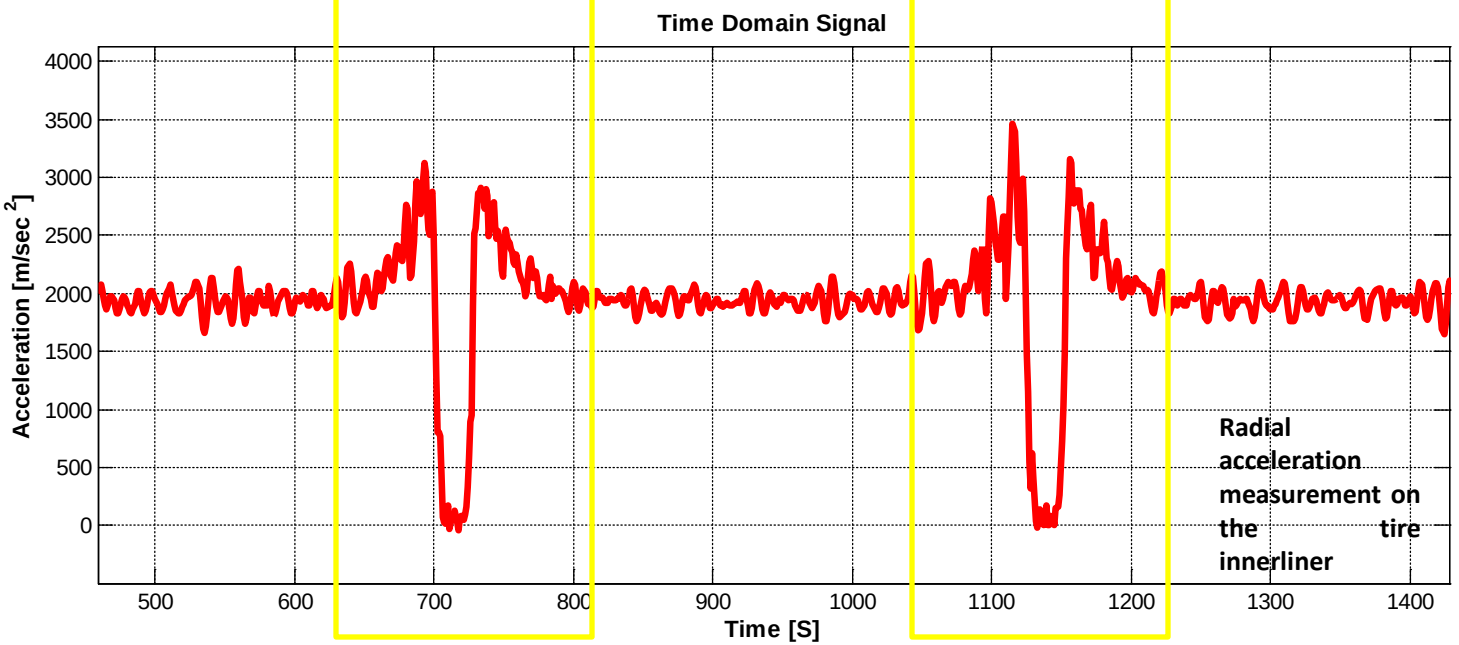


Tire Force Feedback Based Advanced Chassis Control Systems for Vehicle Handling and Active Safety

Single-point Sensing System –
"Useful" Data Available Once Every Tire Revolution







Tire Instrumentation and Testing

Goal: Examine Sensor Performance

Sensor Location

Sensor placed in the crown region

Tri-axial accelerometer

Mounting: Adhesive

Asphalt/Concrete Testing

Gravel Testing

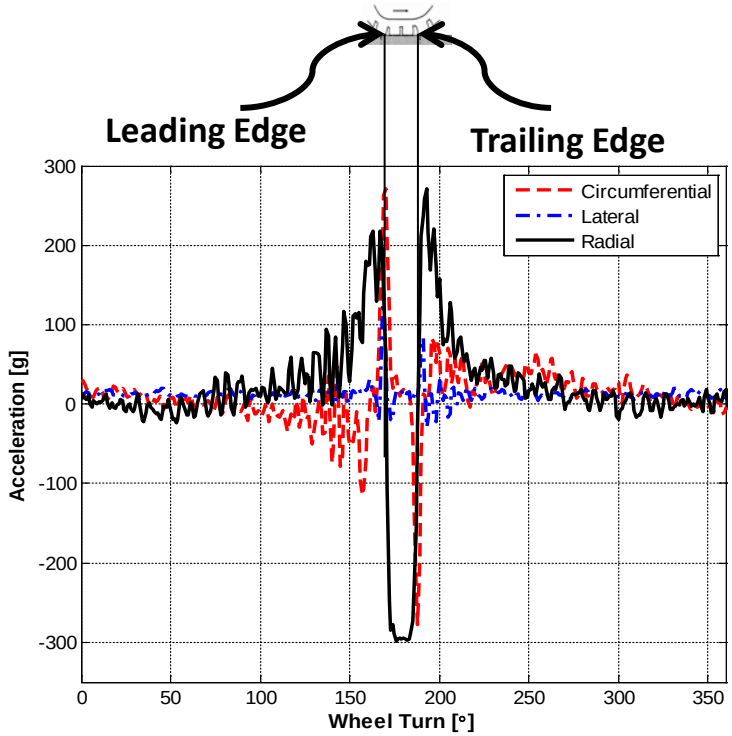
Extensive Outdoor Testing

High Speed Testing

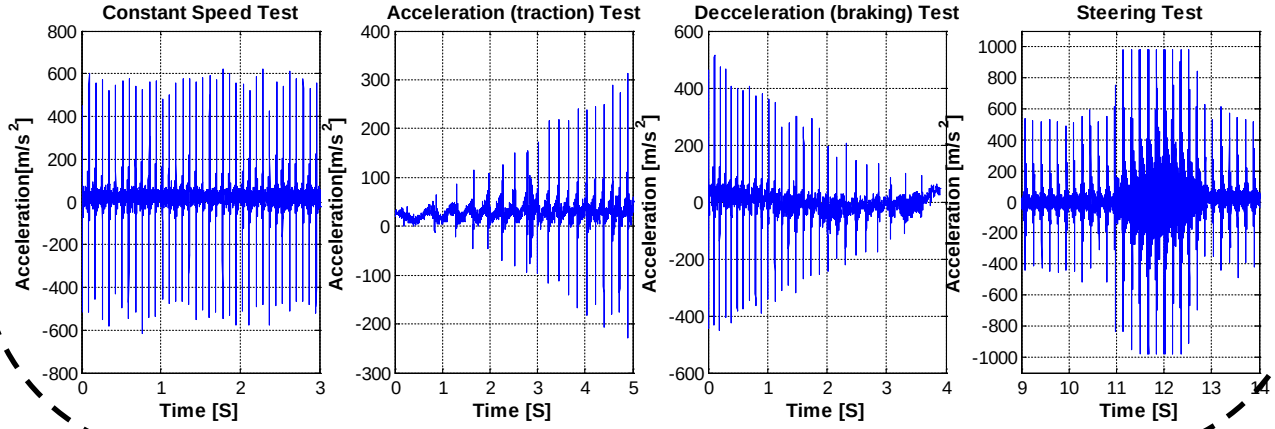
Wet Testing

Algorithm Development Process

RAW SIGNAL



Test Data From Extensive Outdoor Testing



Raw Signal

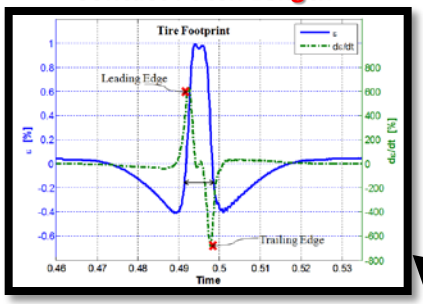
Feature Extraction Algorithm

Valuable Information

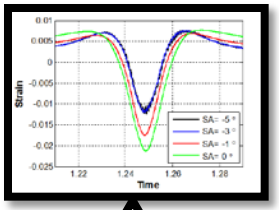
Tire Engineering Dimensions & Characteristics

- Goal: Derive a correlation between the signal and physical phenomenon under investigation

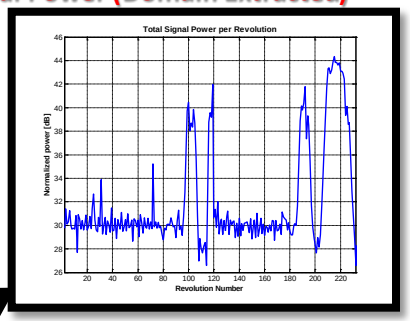
Signal Processing and Feature Extraction



Contact Patch Length



Locus Of Deformation

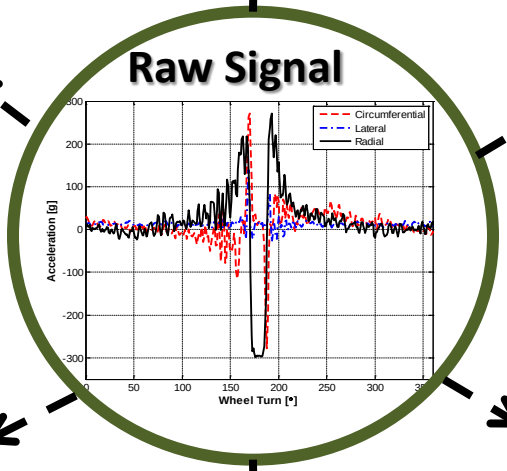


Signal Power (Domain Extracted)

Digital Integrator

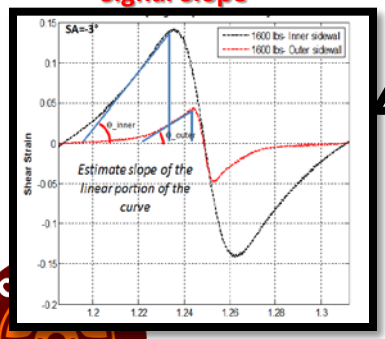
Peak Detection

Signal Amplitude



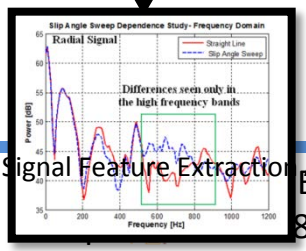
Slope Estimation

Wavelet Transform

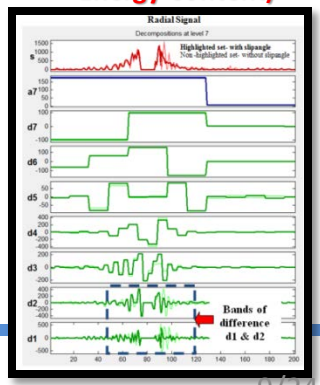


Signal Slope

Power Spectral Density

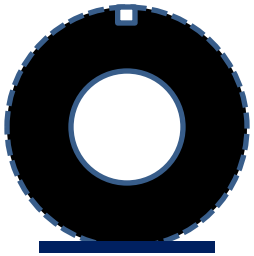


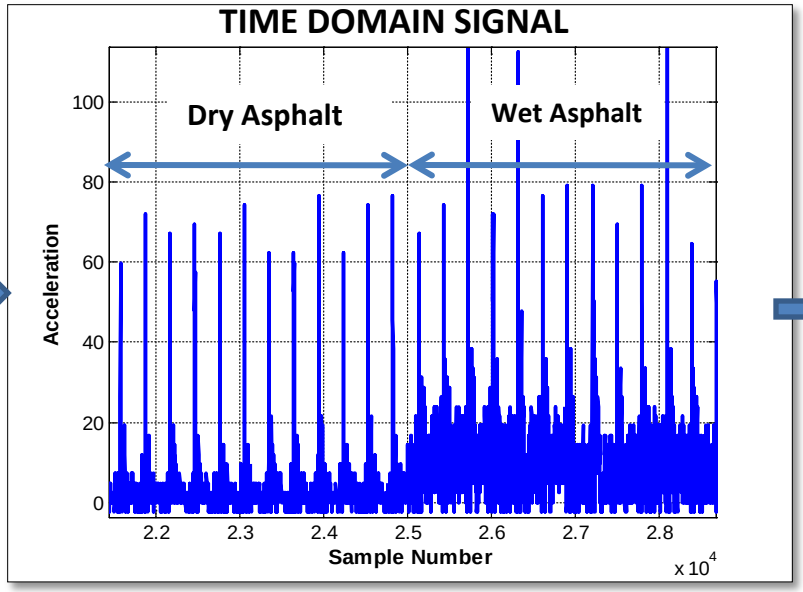
Vibration Ratio



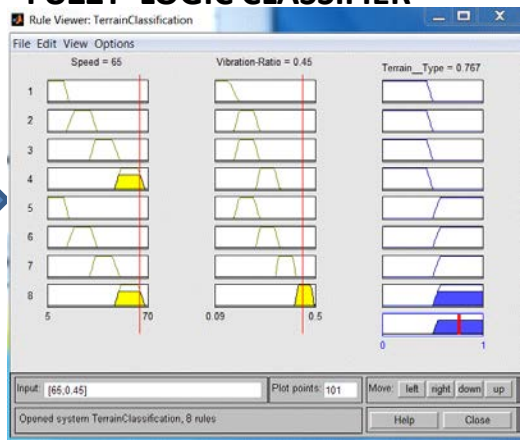
Multiresolution Signal Decomposition (Signal Energy Content)

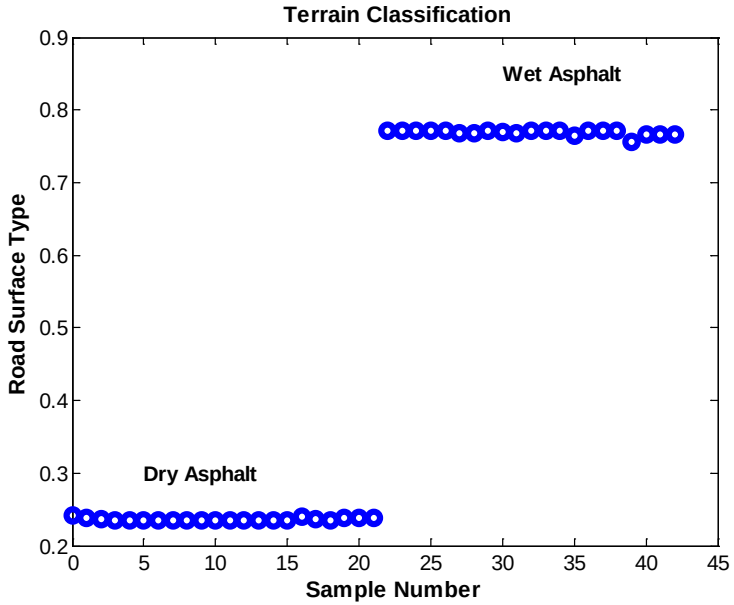
System Performance





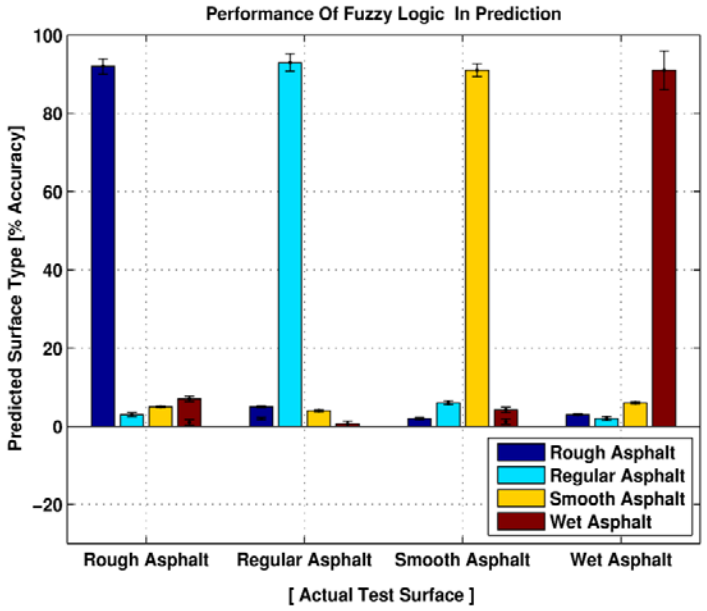
FUZZY LOGIC CLASSIFIER





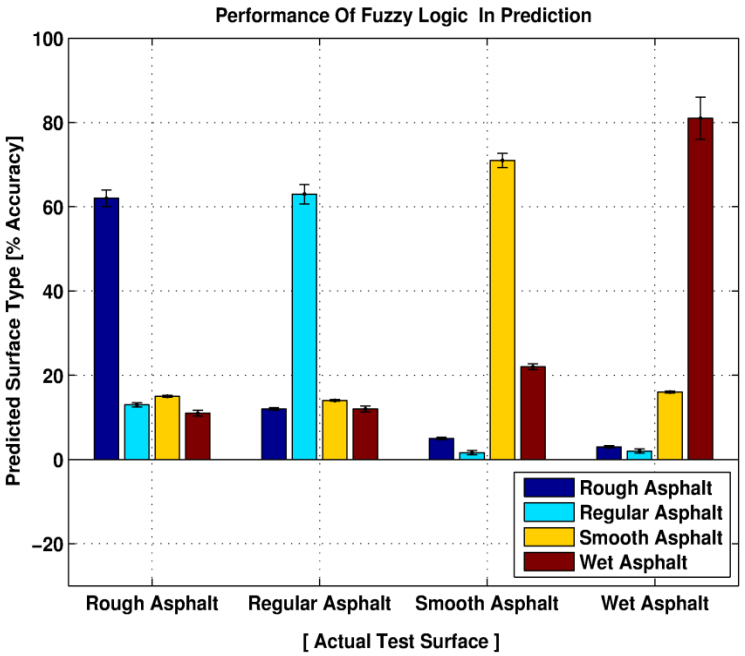
✓**The experimental results show that, the proposed method detects friction change from dry asphalt to wet asphalt while the tire travels at constant speed without braking, accelerating or cornering**

Low-slip conditions



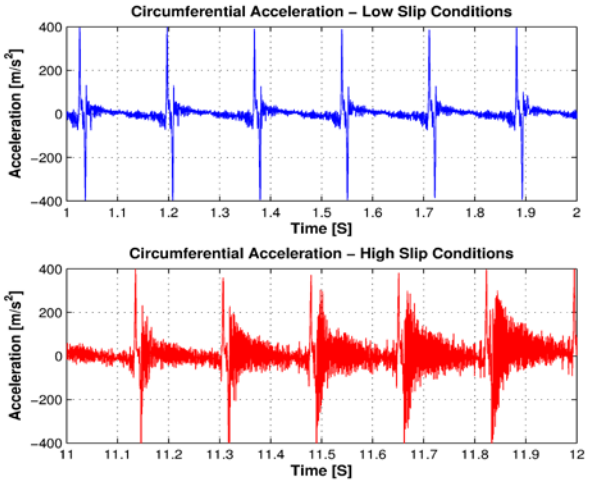
Classifier was successfully able to distinguish between the different road surface conditions

High-slip conditions

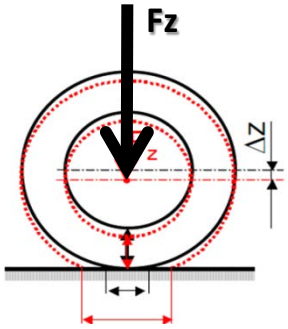


Classifier performance was unsatisfactory

✓**Friction condition can be estimated when vehicle is not necessarily performing any dynamic or handling maneuver.**



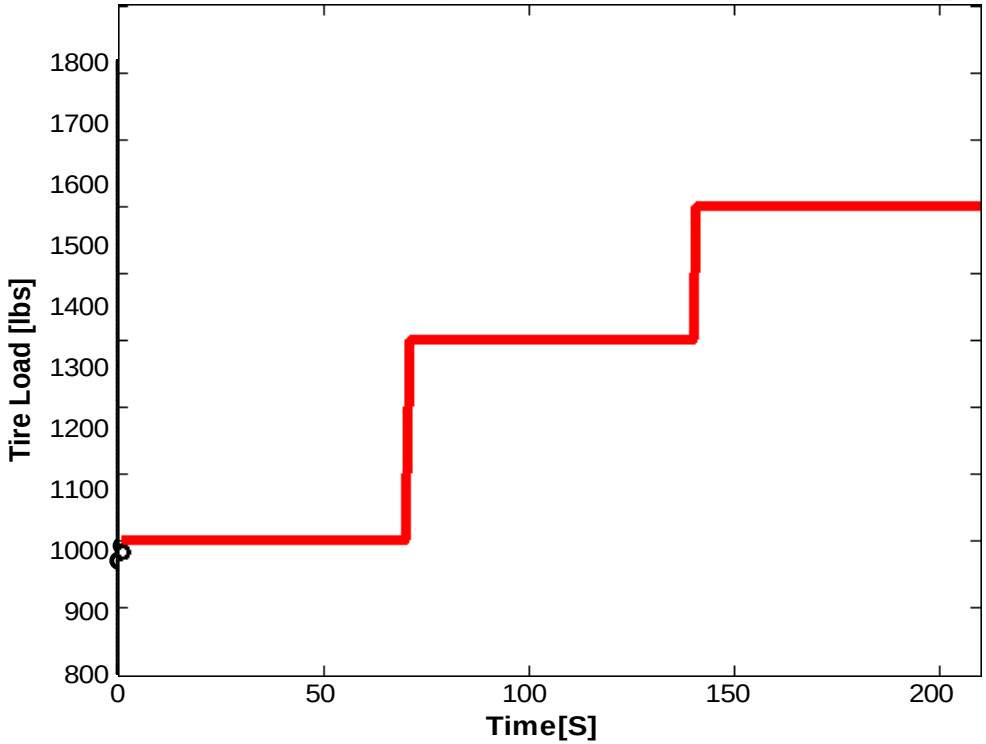
Higher misclassification rates under high slip conditions were attributed to the increased vibration levels in the circumferential acceleration signal due to the stick/slip phenomenon linked to the tread block vibration modes.



Features:
Footprint length
Radial Deformation

Load Estimate

Artificial Neural Network (ANN) Based Parameter Estimation Algorithm

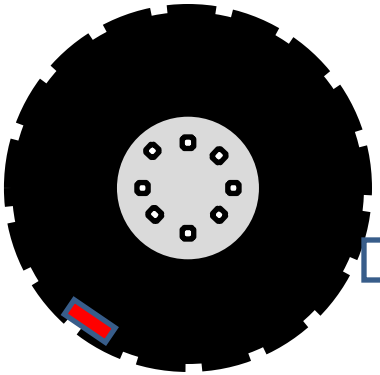


System Performance (Outdoor Tests)

Tire Speed (mph)	System Accuracy (%)
30	90%
45	93%
65	89%

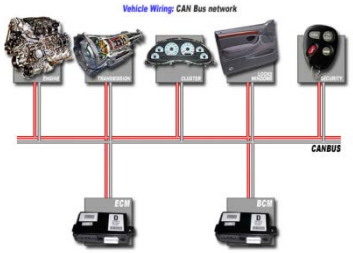
Consequences of Adopting a Single-point Sensing System..

Way Forward: To exploit the fullest potential of the intelligent tire technology, a data fusion approach with more complex data processing algorithms would be required….

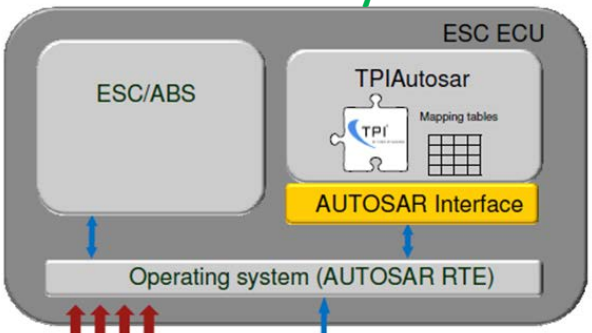


Tire Embedded Sensor

On-Board Vehicle Sensors



Vehicle Control System



sensors

≈ 200 Hz

CAN /Flexray

Data Flow Frequency Mismatch

≈ 5 Hz

Closing Remarks

- A good example of closing the gap between pavement characteristics and tire-vehicle system, is IRI
- Up to this point, a single entity that could close the gap in all aspects of pavement characteristics and tire and vehicle dynamics did not exist
- Center for Tire Research (CenTiRe), with the major OEMs and tire companies as members, can become the research partner with DOTs/FHWA/RPUG to further evaluate the existing pavement characterization methodologies and add new ones to close the gap mentioned above
- Also, partnership with private companies can help with the development and commercialization of the technologies being developed

Thank You!

Questions?

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