VOTERS
Versatile Onboard Traffic Embedded Roaming Sensors

Versatile Onboard Traffic Embedded Roaming Sensors

Network-wide Infrastructure Solutions

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National Pavement Evaluation Conference 2014
Blacksburg, Virginia

VOTERS[1] Vision

Versatile Onboard Traffic Embedded Roaming Sensors

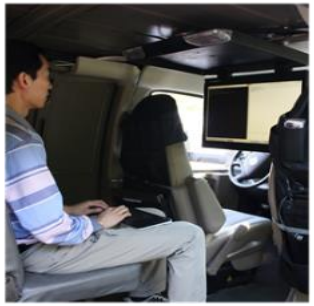
- **VOTERS Vehicle** collects Sensor Data, automatically measuring ***Surface and Subsurface*** Roadway Condition Information traveling around a city at ***Traffic Speed***
- Accurately registers all data ***geographically*** and in ***time***
- Data or Results are transferred to a ***Control and Visualization Center*** for further analysis, visualization, and decision making

- No Traffic blockage
- Fully Automated (except driver)
- Fast (up to 100 miles/day, single lane)
- Very cost competitive
- Light weight sensor systems
- Frequent updates possible (e.g. 6 months)

[1] *$18M 5-year NIST funded project*

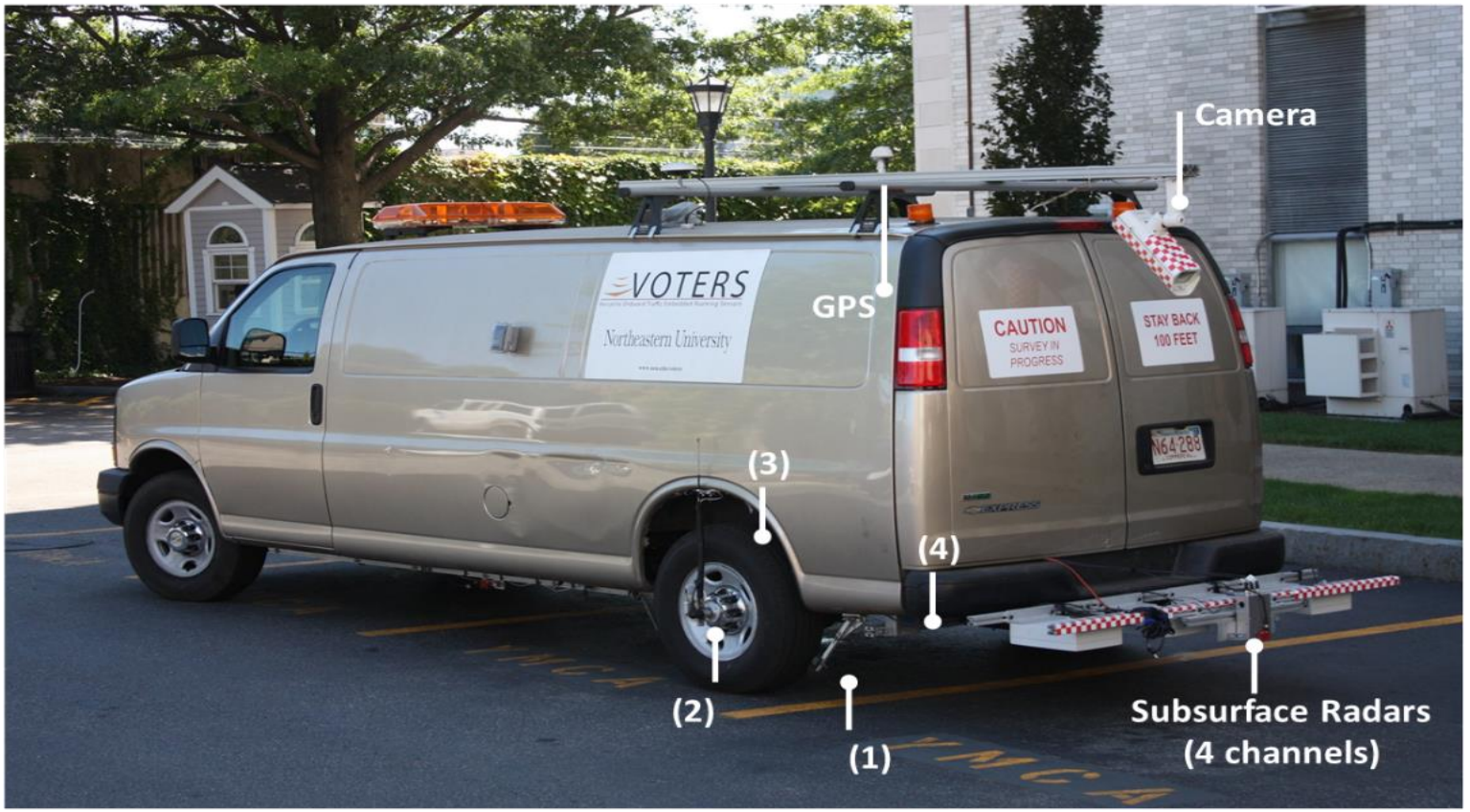
VOTERS Prototype

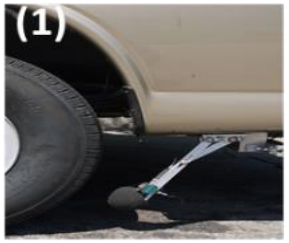
Portable real-time monitor



System control monitor

Data acquisition and processing





Directional Microphone

Dynamic tire pressure sensor

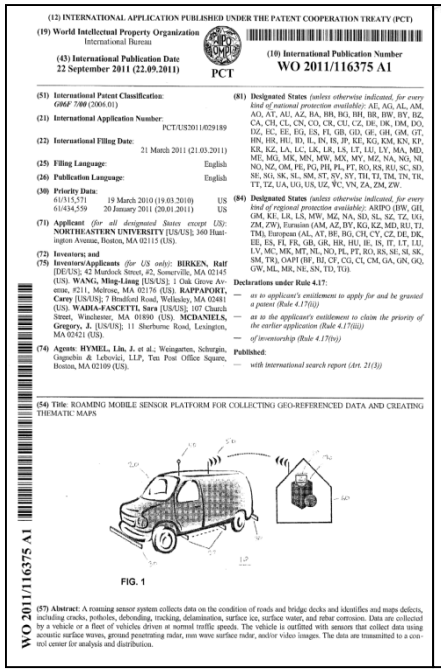
Rear axle accelerometer

Surface radar array (5 sensors)

Technology	Measurements	Specifications	Picture
Directional Microphone	**Friction** **Raveling** **Bleeding** **Macro Texture Index** **Polished Aggregate**	Sensor height: ½ - 3 inch Sampling Rate: 2 - 200 KHz Sensitivity: 44 - 52 mv/Pa	
Dynamic Tire Pressure Sensor (DTPS)	**Roughness** **Road Profile** **Road Height Variations** **International Roughness Index (IRI)**	Frequency: 0.5 Hz - 20 KHz Sampling Rate: 2 - 200 KHz Dynamic Pressure Resolution: 0.00002 psi	
Camera	**Crack Density** **Crack Types** **Patch Density** **Potholes** **Shoving** **Other Surface Feature**	Resolution: 2.82 Megapixel Speed: Gigabit Ethernet 40 Frames/sec	
Millimeter-Wave Radar	**Rutting depth** **Bleeding** **Moisture** **Ice** **Material identification** **Longitudinal & Transversal Profile**	Operation: 24 GHz Arrays: 5 channels	
Ground Penetrating Radar	**Rebar Corrosion of Bridge Decks** **Layer Depth** **Vertical Profile** **Subsurface Feature Identification (delamination, potholes, etc.)** **Subsurface Moisture**	Frequency: 0.8 - 5 GHz Data rate: 1000 trace/sec Low cost Low power Small	

Patent Filed and Published

1. Roaming Mobile Sensing Platform for Collecting Geo-referenced Data and Thematic Maps
2. Real-Time Wireless Dynamic Tire Pressure Sensor and Energy Harvesting System
3. Real-Time Pavement Profile Sensing System Using Air-Coupled Surface Wave
4. Configurable mm-wave Integrated Array Radar in a Compact Package



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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International Bureau

(43) International Publication Date
22 September 2011 (22.09.2011)

PCT

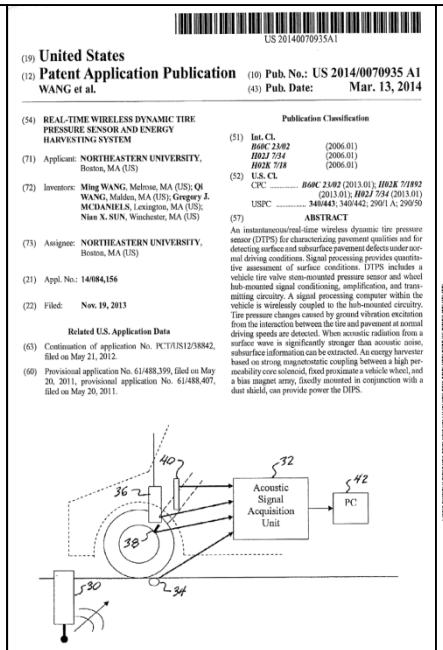
(10) International Publication Number
WO 2011/116375 A1

(54) Title: ROAMING MOBILE SENSOR PLATFORM FOR COLLECTING GEO-REFERENCED DATA AND CREATING THEMATIC MAPS

FIG. 1

WO 2011/116375 A1

(1)



US 20140070935A1

(19) United States

(12) Patent Application Publication

WANG et al.

(10) Pub. No.: US 2014/0070935 A1

(43) Pub. Date: Mar. 13, 2014

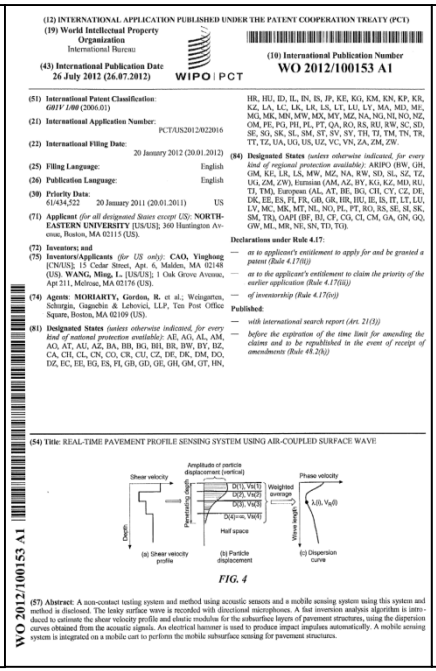
(54) REAL-TIME WIRELESS DYNAMIC TIRE PRESSURE SENSOR AND ENERGY HARVESTING SYSTEM

Publication Classification

Acoustic Signal Acquisition Unit

PC

(2)



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
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(43) International Publication Date
26 July 2012 (26.07.2012)

WIPO | PCT

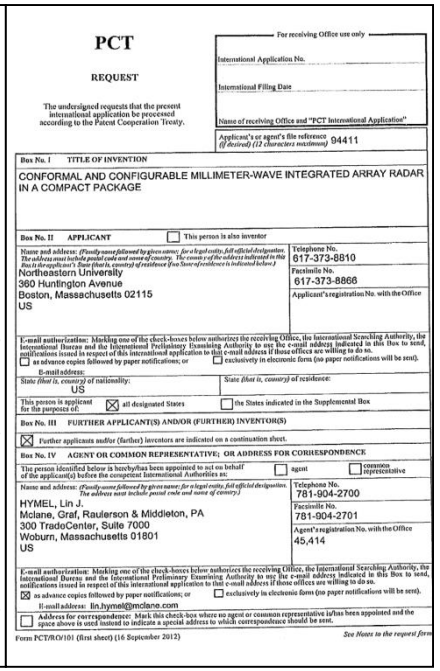
(10) International Publication Number
WO 2012/100153 A1

(54) Title: REAL-TIME PAVEMENT PROFILE SENSING SYSTEM USING AIR-COUPLED SURFACE WAVE

FIG. 4

WO 2012/100153 A1

(3)



PCT

REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only

International Application No.

International Filing Date

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference (if desired) (12 characters maximum) 94411

Box No. I TITLE OF INVENTION

CONFORMAL AND CONFIGURABLE MILLIMETER-WAVE INTEGRATED ARRAY RADAR IN A COMPACT PACKAGE

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Agent's registration No. with the Office 45,414

Form PCT/RO/101 (first sheet) (16 September 2012)

(4)

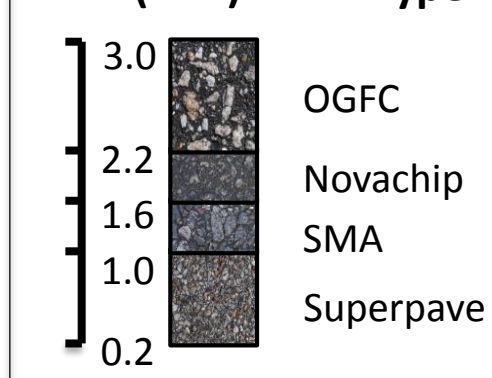
VOTERS Sensor Systems

- Acoustic Microphone
- Dynamic Tire Pressure Sensor
- Optical Sensor
- K-band Surface Radar
- Subsurface Radar

Acoustic Microphone

Purpose

- Road Mean Texture Depth (*MTD*)
- Pavement Condition Rating (Raveling/Bleeding)
- Friction Coefficient



NCAT (Interstate Highway)

Hardware

Microphone

- Sensor Location: driver side, rear tire
- Sensor Height: 1/2 to 3 inch
- Sampling Rate: 2 – 200 kHz
- Sensitivity: 44 – 52 mV/Pa

Processing Flowchart

Collect data → Sound generated by tire/road interaction *plus other noise (engine, wind, etc)*

↓

FFT → Frequency spectrum

↓

PCA → Extract road texture information from large variation with respect to frequency

↓

PCA energy (e) → Integration of the first PC over the frequency ranged between 140 to 700 Hz

↓

Fundamental Equation → $MTD = 0.2 + 1.55e_n + 0.44\,v_n + 0.76\,e_n v_n$

PCA – Principal Component Analysis
PC – Principal Component
e_n – normalized PCA energy, 0~1
v_n – normalized velocity, 0~1

Dynamic Tire Pressure Sensor (DTPS)

Purpose

- Road Profile Measurement
- International Roughness Index Assessment

Hardware

Accelerometer

Processing Flowchart

Collect data → DTPS and Acceleration Subtract DC gain

↓

FFT → Frequency spectrum

↓

Transfer Function → Calculate dynamic tire pressure due to road profile

↓

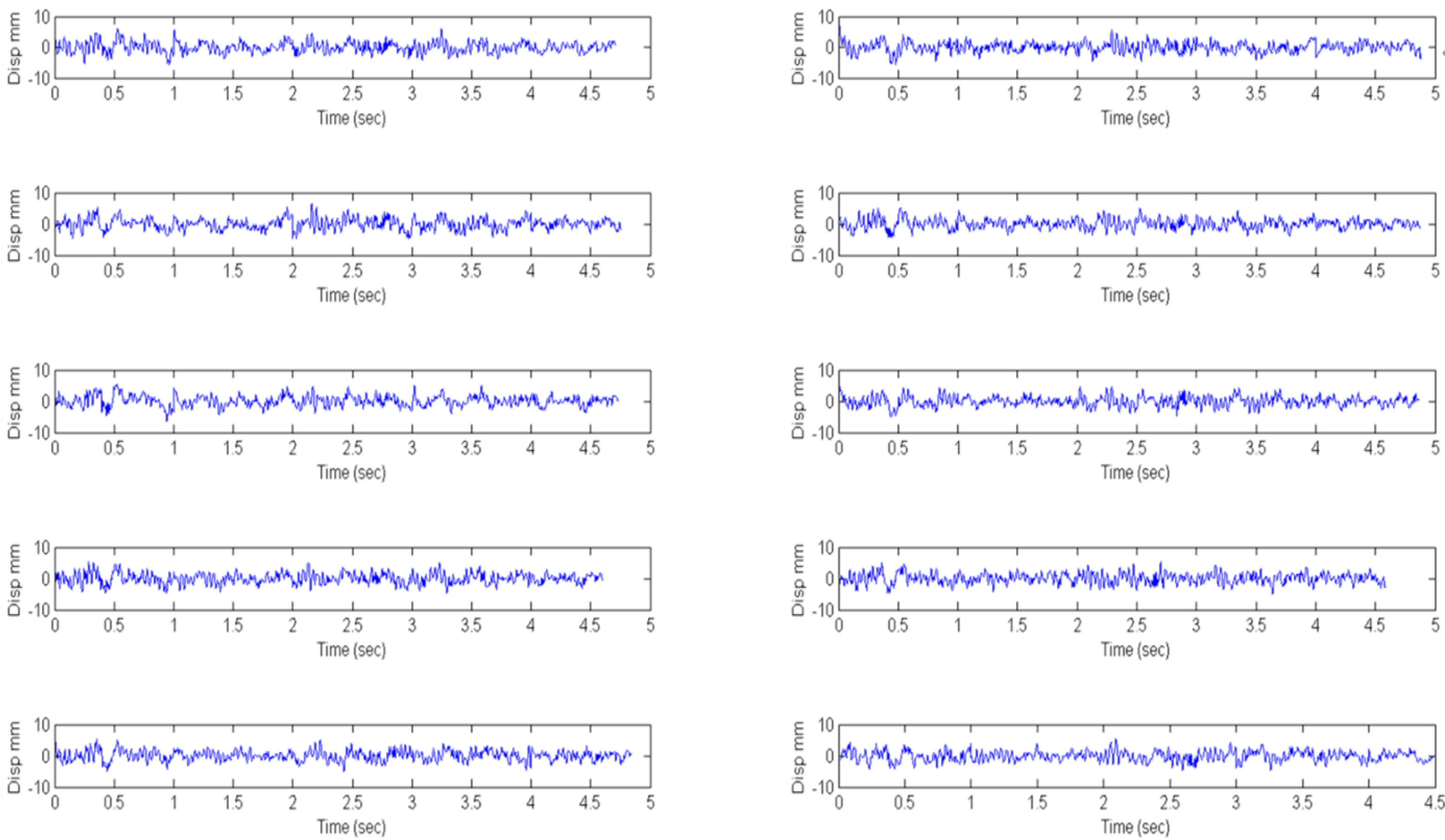
iFFT → Road Profile

↓

IRI → **Quarter Car Model Applied based on ASTM standard E1926-08**

IRI result of Site 3 (medium smooth)

Speed mph	45	45	45	45	45	45	45	45	45	45	30	Average	Standard deviation
IRI in/mile	103.5	88.9	90.6	107.9	91.7	92.2	87.5	102.8	96.0	86.7	98.2	95.1	7.0
IRI m/km	1.63	1.40	1.43	1.70	1.45	1.46	1.38	1.62	1.52	1.37	1.55	1.50	0.11



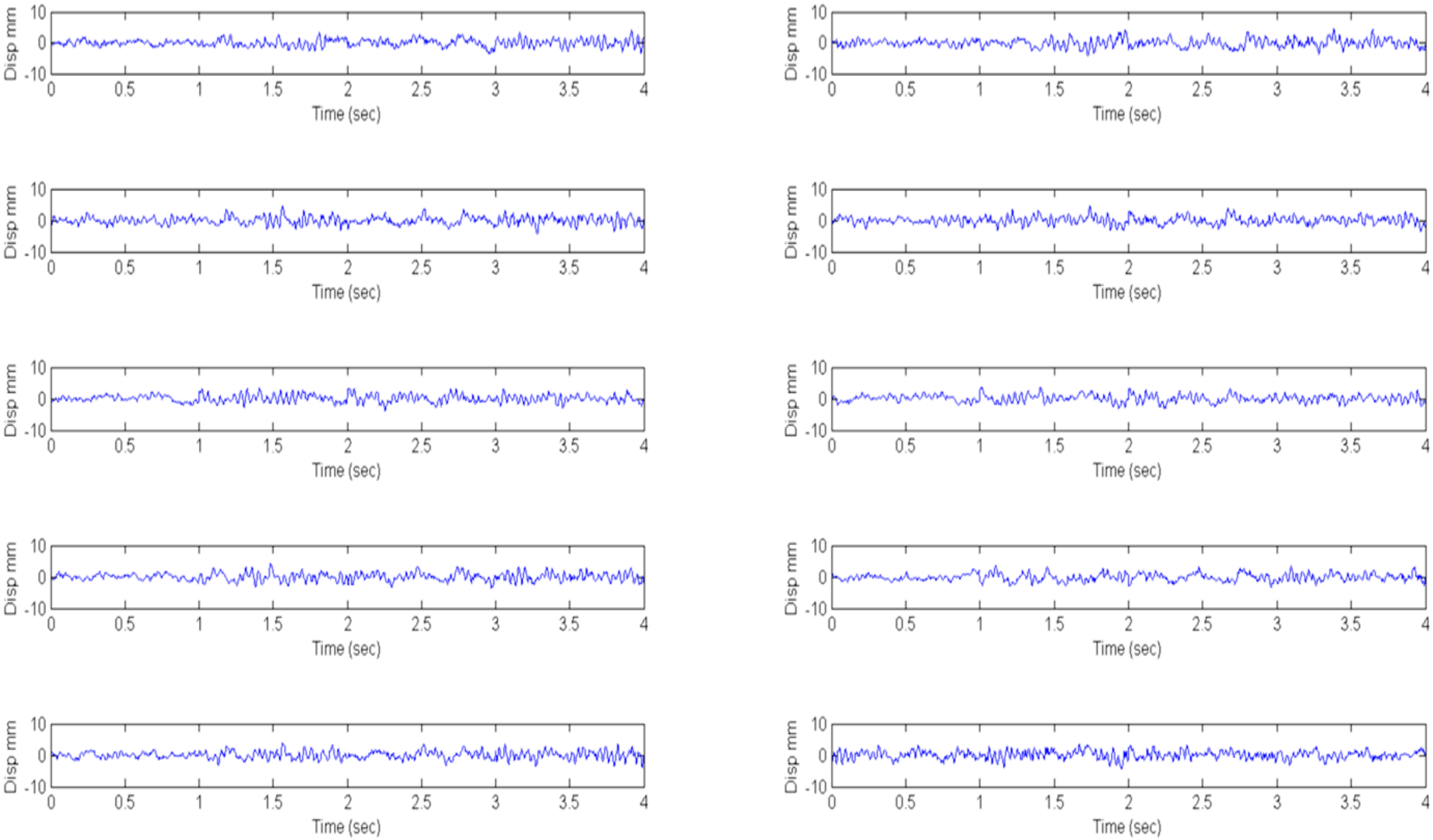
Profile plot

Location reference: GPS

Position Accuracy 1 sec

IRI result of Site 5 (smooth)

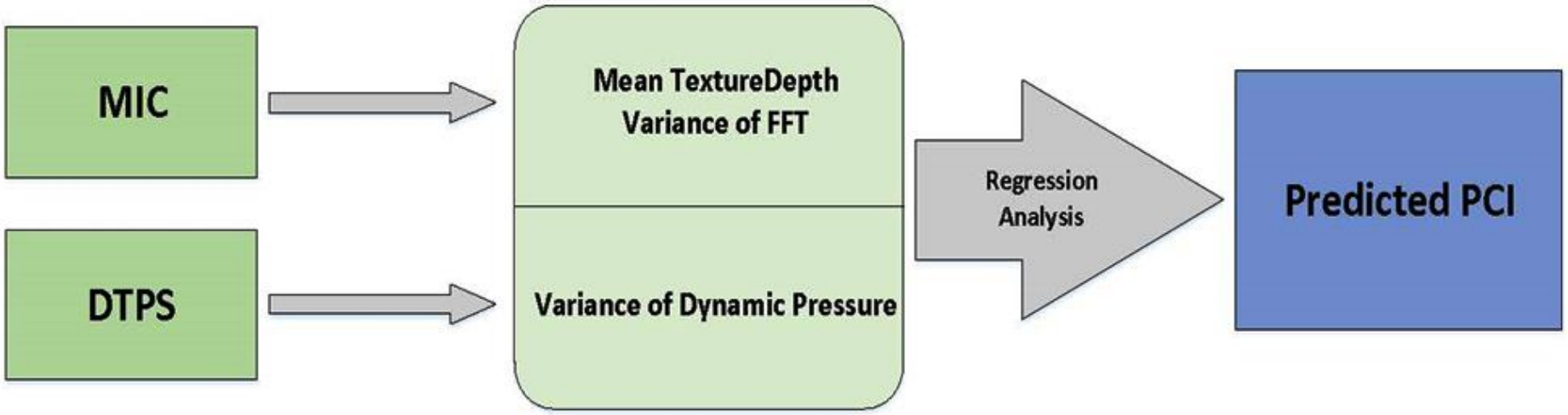
Speed mph	45	45	45	45	45	45	45	45	45	45	30	Average	Standard deviation
IRI in/mile	79.8	82.3	79.9	77.9	80.5	76.3	72.0	77.6	72.8	75.4	72.1	76.9	3.4
IRI m/km	1.26	1.28	1.26	1.23	1.27	1.20	1.14	1.23	1.15	1.19	1.14	1.21	0.05

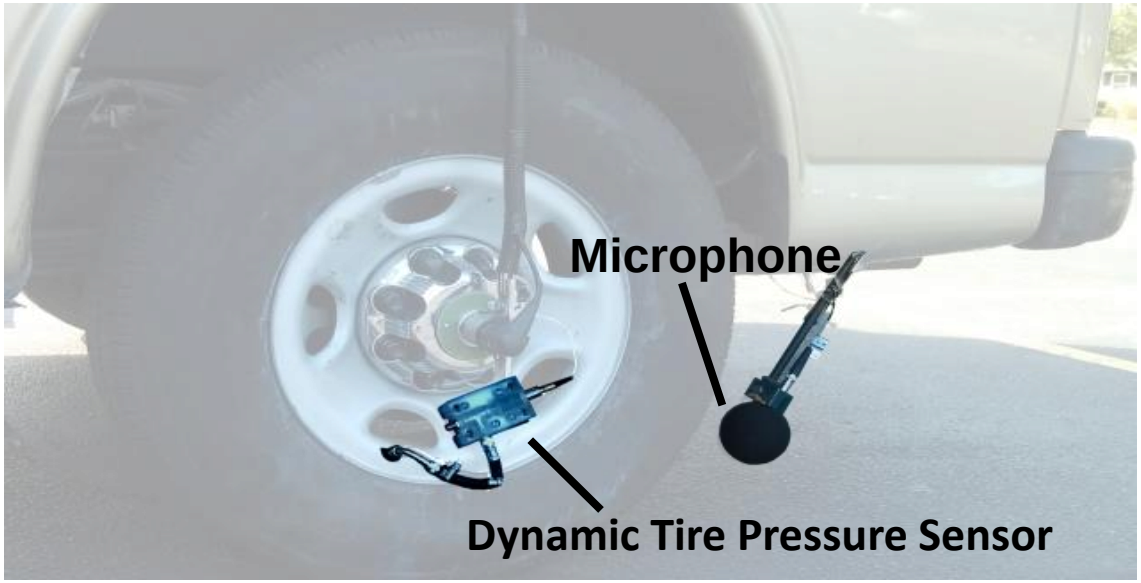


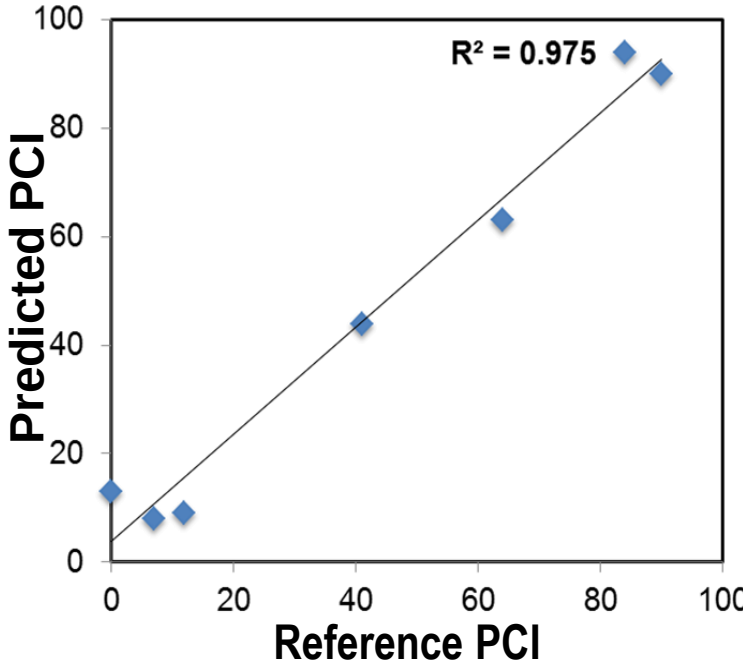
Profile plot

Location reference: GPS

Position Accuracy 1 sec


MIC
DTPS
Mean TextureDepth
Variance of FFT
Variance of Dynamic Pressure
Regression Analysis
Predicted PCI


Microphone
Dynamic Tire Pressure Sensor


R² = 0.975
Predicted PCI
Reference PCI
0
20
40
60
80
100

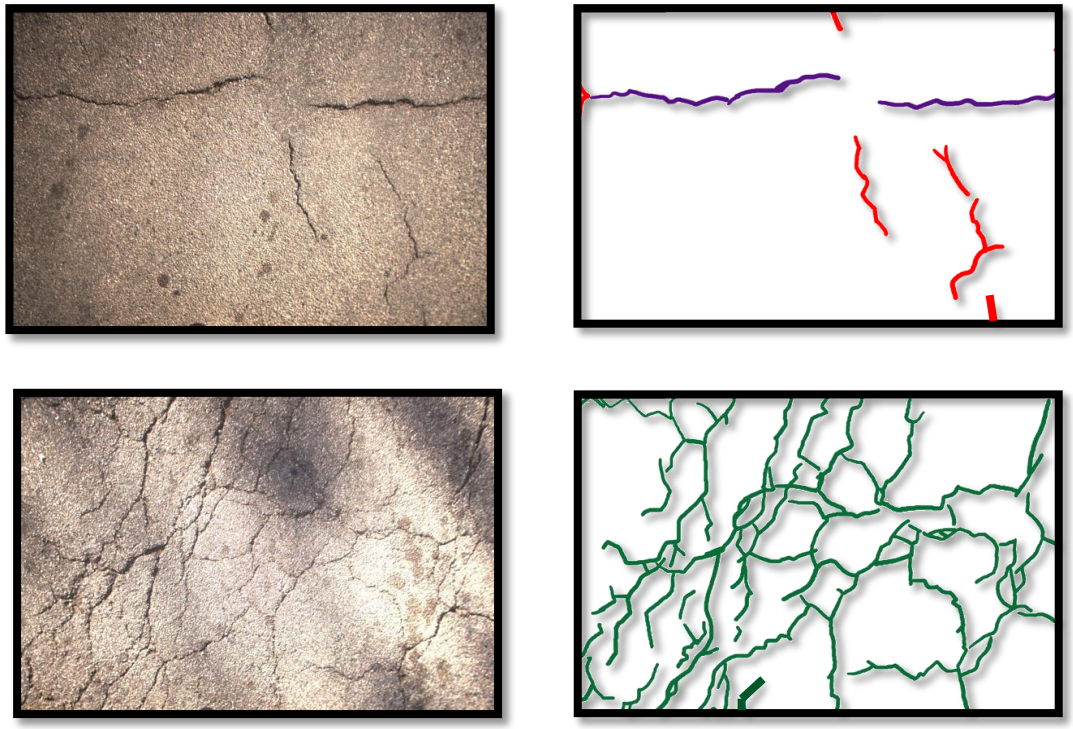
Optical Sensor

Purpose

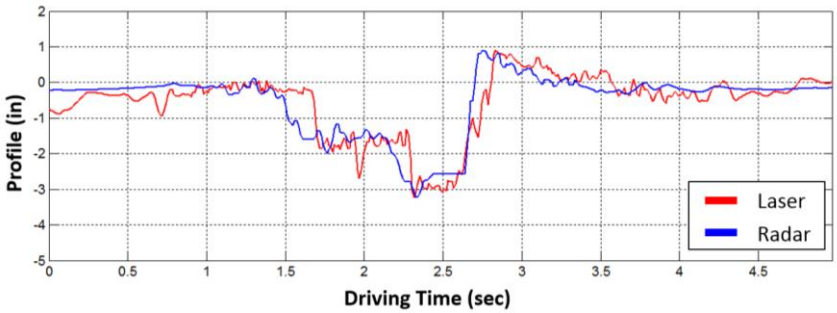
- Detecting Surface Cracks
- Identifying Type of Cracks
- Calculating Crack Density

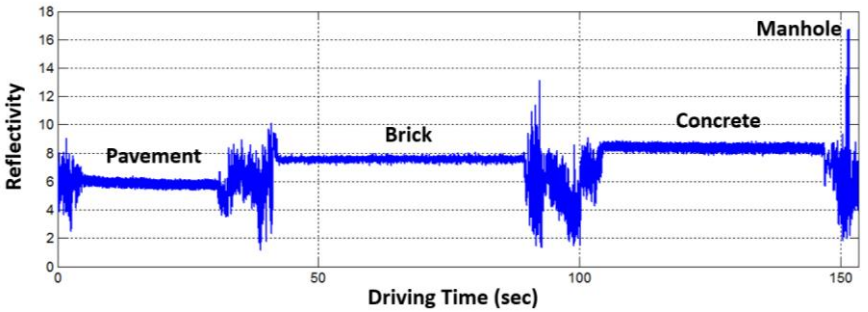
Set-up

Example Results



K-Band Surface Radar

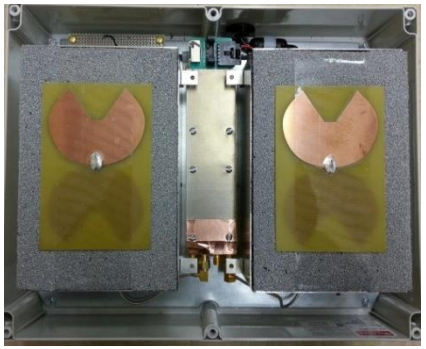


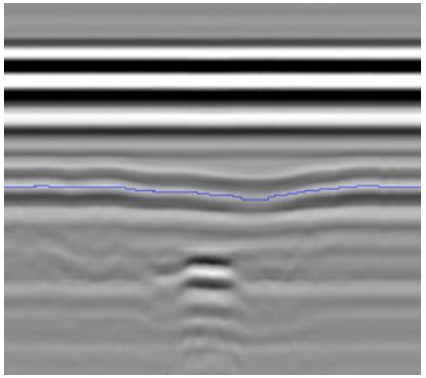


Gen-3 Earth Science Systems GPR System

ESSential Underground Information

- This custom air-coupled GPR system is fast, low-cost, low-power, and small compared to similar COTS systems
- Features
  - Very good fidelity: **2-5 GHz**
  - Dynamic range: **105 dB**
  - Novel 100 GHz 1 bit sampler
    - Sampling rate: 1/32ps
  - Up to **1000 traces/s**, time or distance triggered
  - Power: 7W at 5 VDC
  - Dimensions: 300 x 230 x 85 mm
  - Uses NEU custom designed bow-tie antennas
  - Array Capabilities (16 x 16)
    - Diverse data sets in frequency, geometry, and polarization
    - Simultaneous recording on all receivers
  - Designed for FCC 02-48 compliance
  - HDF5 open file format for large datasets
- Applications
  - Pavement layer thickness and dielectric constant tracking, identification of subsurface voids, moisture pockets, and other defect





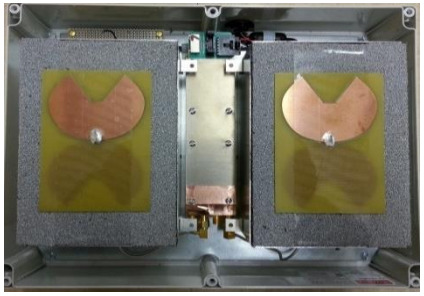
Subsurface Radar System

Purpose

- Layer thickness and dielectric constant
- Location of distress or/and patches
- Pre-pothole conditions and internal moisture

Hardware and Set-up

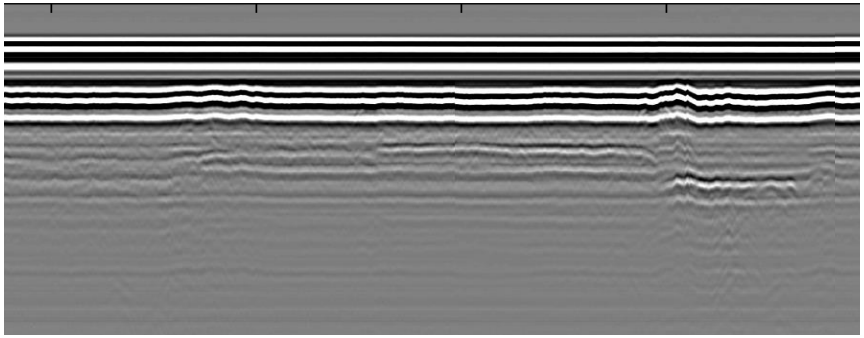
a. ESS Gen-3 Radar and Computer

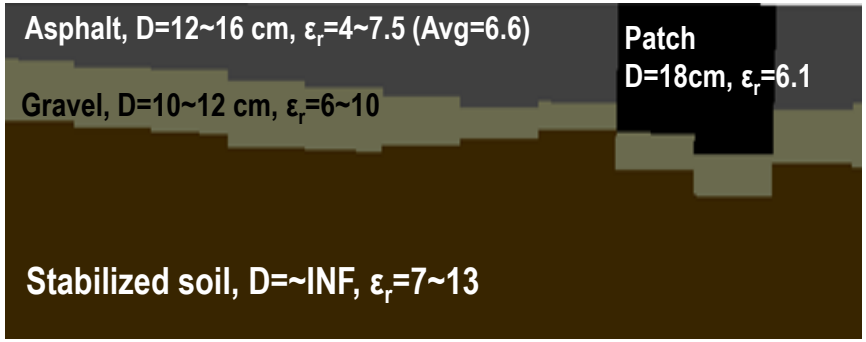


b. ESS Gen-3 radar (Inside box)

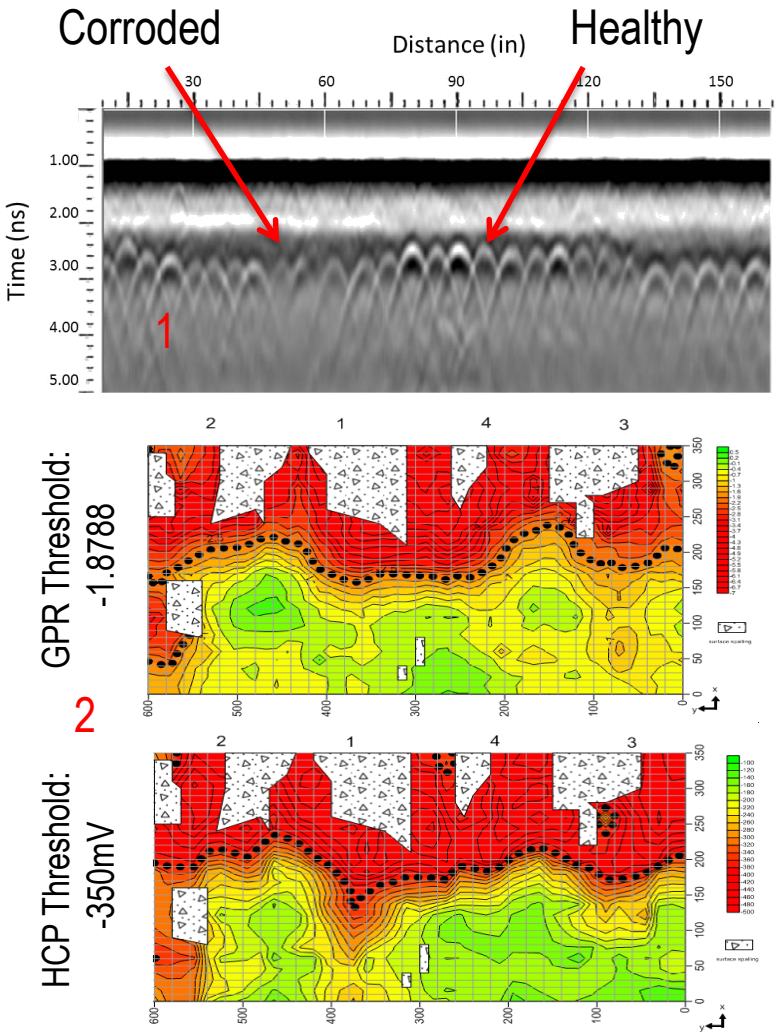
Test Results

Forsyth St., Boston, MA

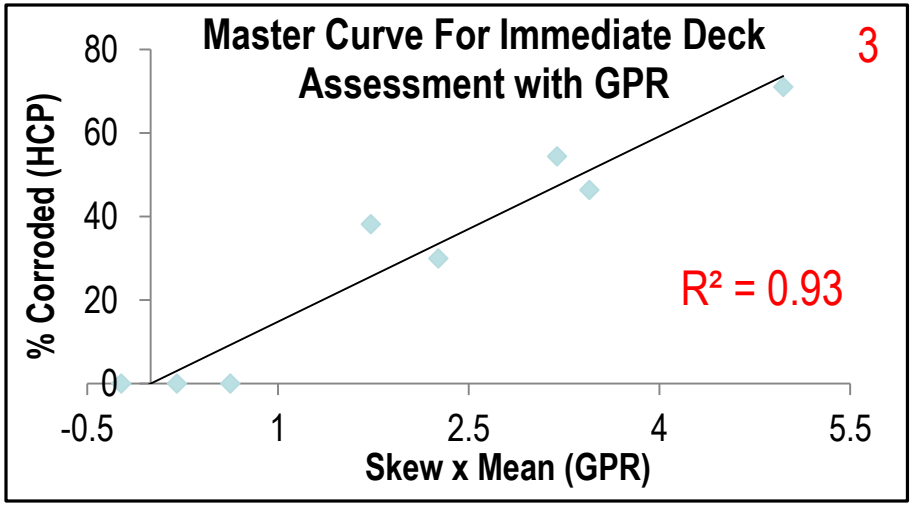




Drive-by Bridge Deck Assessment



- **Rebar reflection amplitudes** of corroded areas are much lower (faint) than healthy areas (1)
- GPR can detect corroded and healthy areas by comparing the reflection amplitudes to half-cell potential (2)
- Statistical analysis of GPR rebar amplitudes allow for immediate deck condition assessment using mobile high-speed radar (3)



VOTERS GIS SYSTEMS

PAVEment MONitoring System

Mapping and Reporting

Web-access

Data Creation

Analysis

PAVEMON

Visualization

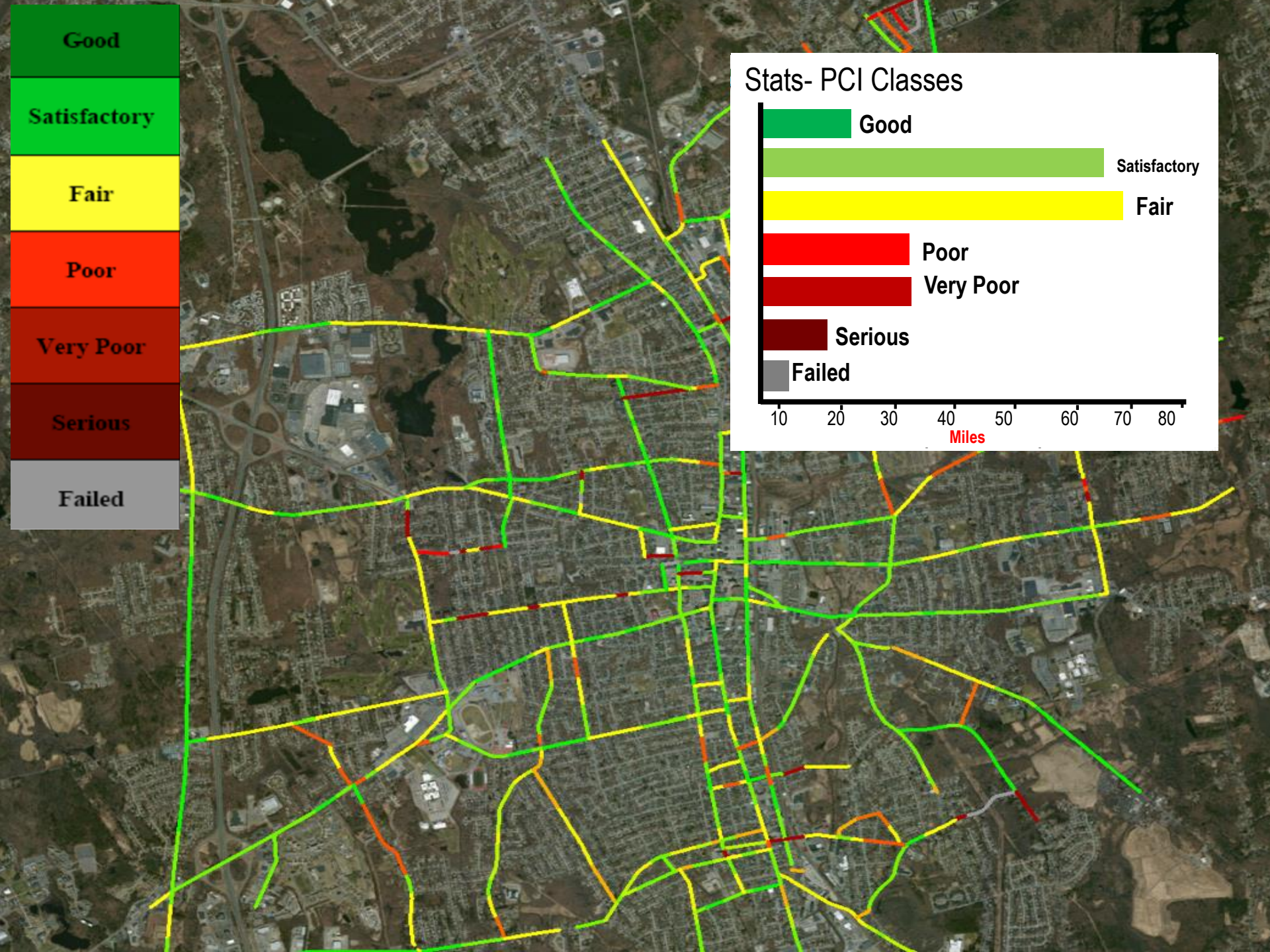
Database

Real-time Display

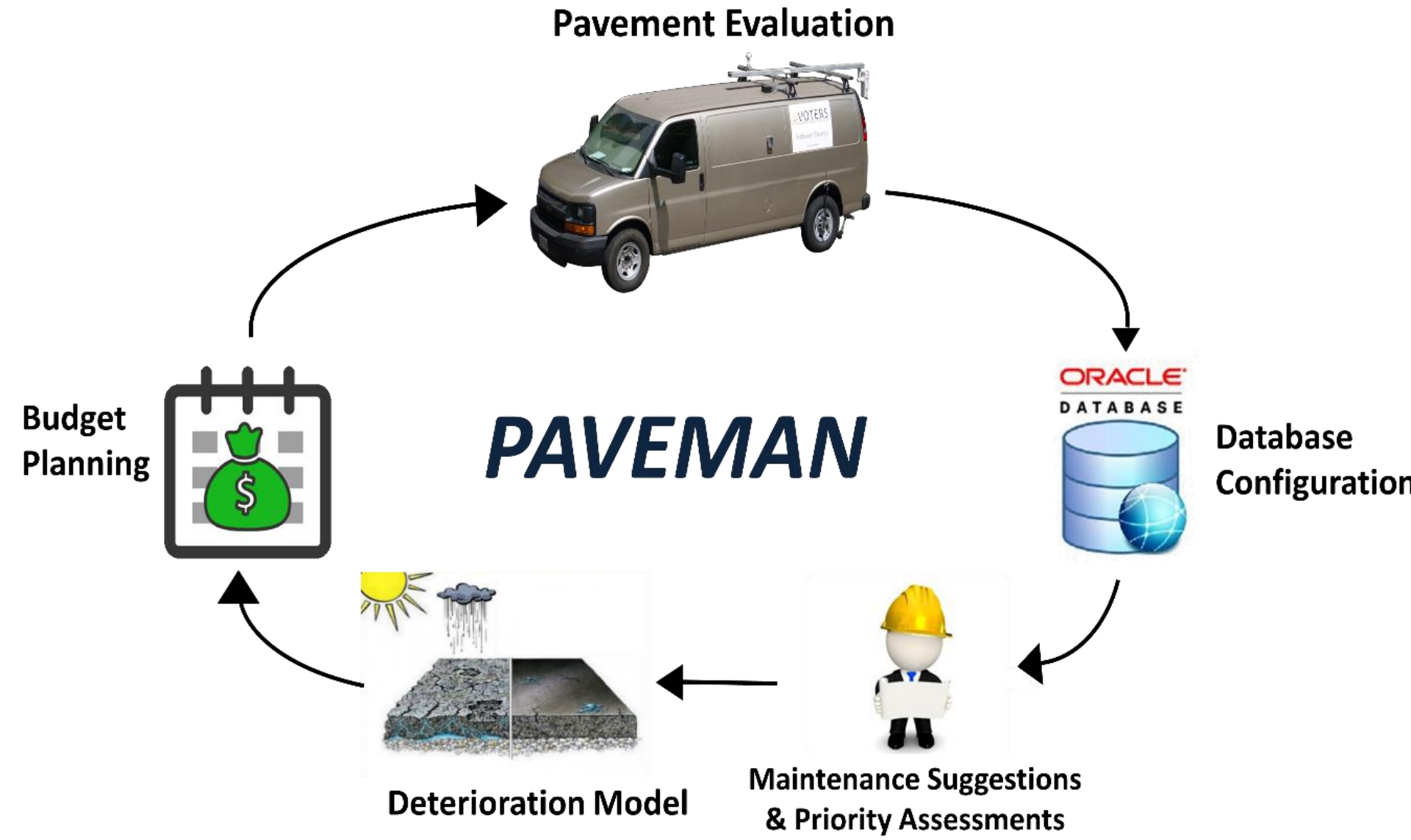
ORACLE DATABASE

*PAVE*ment *MAN*agement System

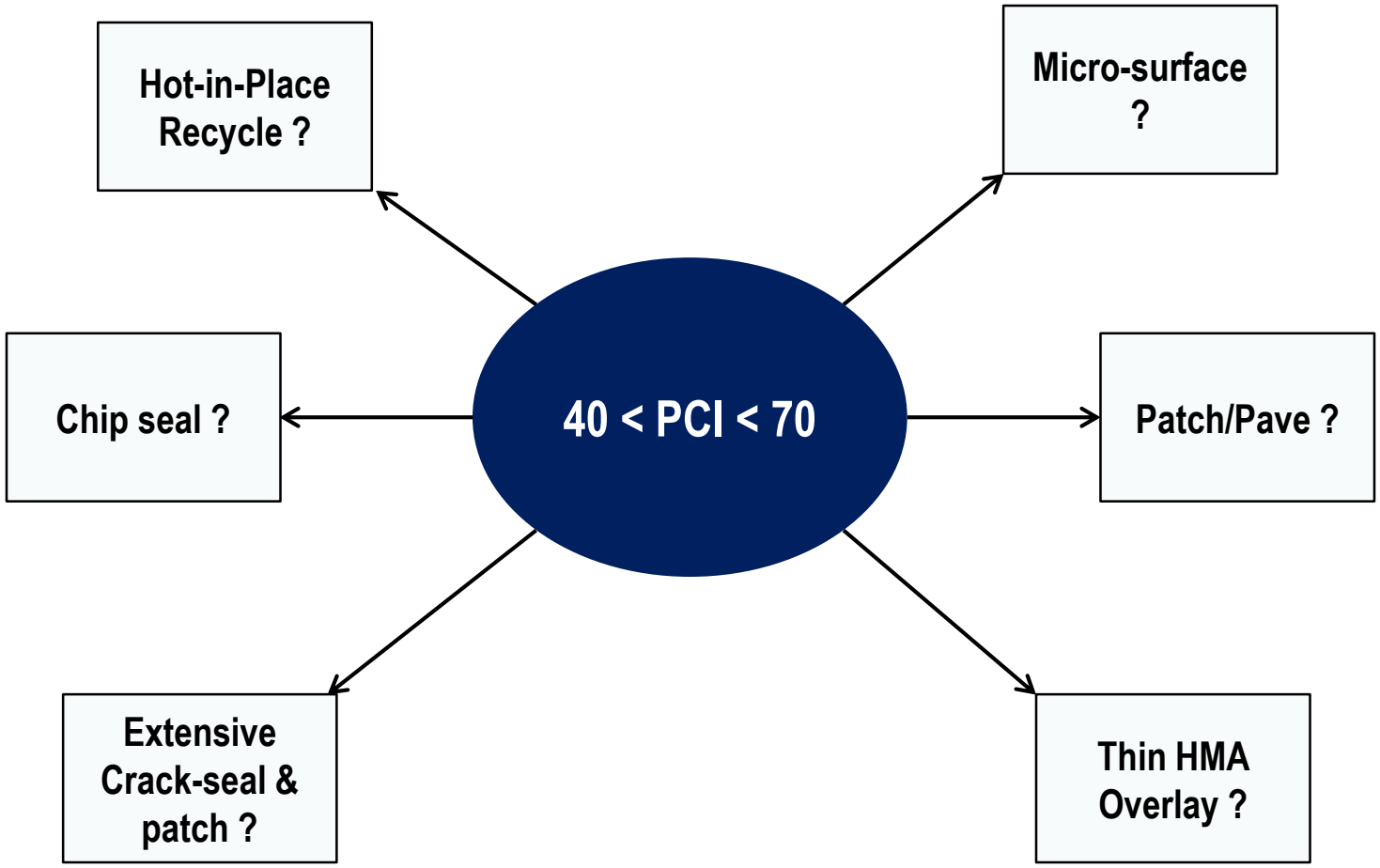
Damaged Area
Repair Activity
Cost ($)
Priority


Good
Satisfactory
Fair
Poor
Very Poor
Serious
Failed
Stats- PCI Classes
Good
Satisfactory
Fair
Poor
Very Poor
Serious
Failed
10
20
30
40
50
60
70
80
Miles

*PAVE*ment *MAN*agement System



Possible treatments for intermediate PCI



Suggest the best treatment using VOTERS data

MTD

Road Profile

Crack Density

Rutting Depth

Patch/pave

Extensive Crack-seal & patch

Hot-in-Place Recycle

VOTERS
Versatile Onboard Traffic Embedded Roaming Sensors

Technology Breakthroughs

- Road surface assessment by listening to the tire-road interaction with microphones (inside and outside the tire)
- IRI (roughness) from Dynamic Tire Pressure Sensor even on urban roads
- PCI equivalent from fused multi-modal sensor data
- Road subsurface information through fast air-coupled GPR at traffic speeds providing layering, defects, and moisture information
- K-band radar for pavement surface inspections
- Scalable software architecture for an intelligent multi-modal multi-sensor mobile platform[1]
- Automation of many processing and interpretation algorithms
- PAVEMON – GIS-based online PAVEment MONitoring System
- PAVEMAN – GIS-based online PAVEment MANagement System
  - Data-driven approach for maintenance and repair suggestions

[1]*Zhang, Jiaxing, Qiu, Hanjiao, Shahini Shamsabadi, Salar, Birken, Ralf, and Schirner, Gunar, 2014, SIROM^3: A scalable intelligent Roaming Multi-Modal Multi-Sensor Framework: Proceedings of ACM/IEEE 5th International Conference on Cyber-Physical Systems (ICCPS), Berlin, Germany, April 14-17, 2014.*

VOTERS

Versatile Onboard Traffic Embedded Roaming Sensors

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Thank you!

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Supporting Organizations

Northeastern