MICHIGAN STATE UNIVERSITY

CIVIL & ENVIRONMENTAL ENGINEERING

Smart Sensing Technology for Infrastructure Monitoring

Supported by FHWA and USDOT

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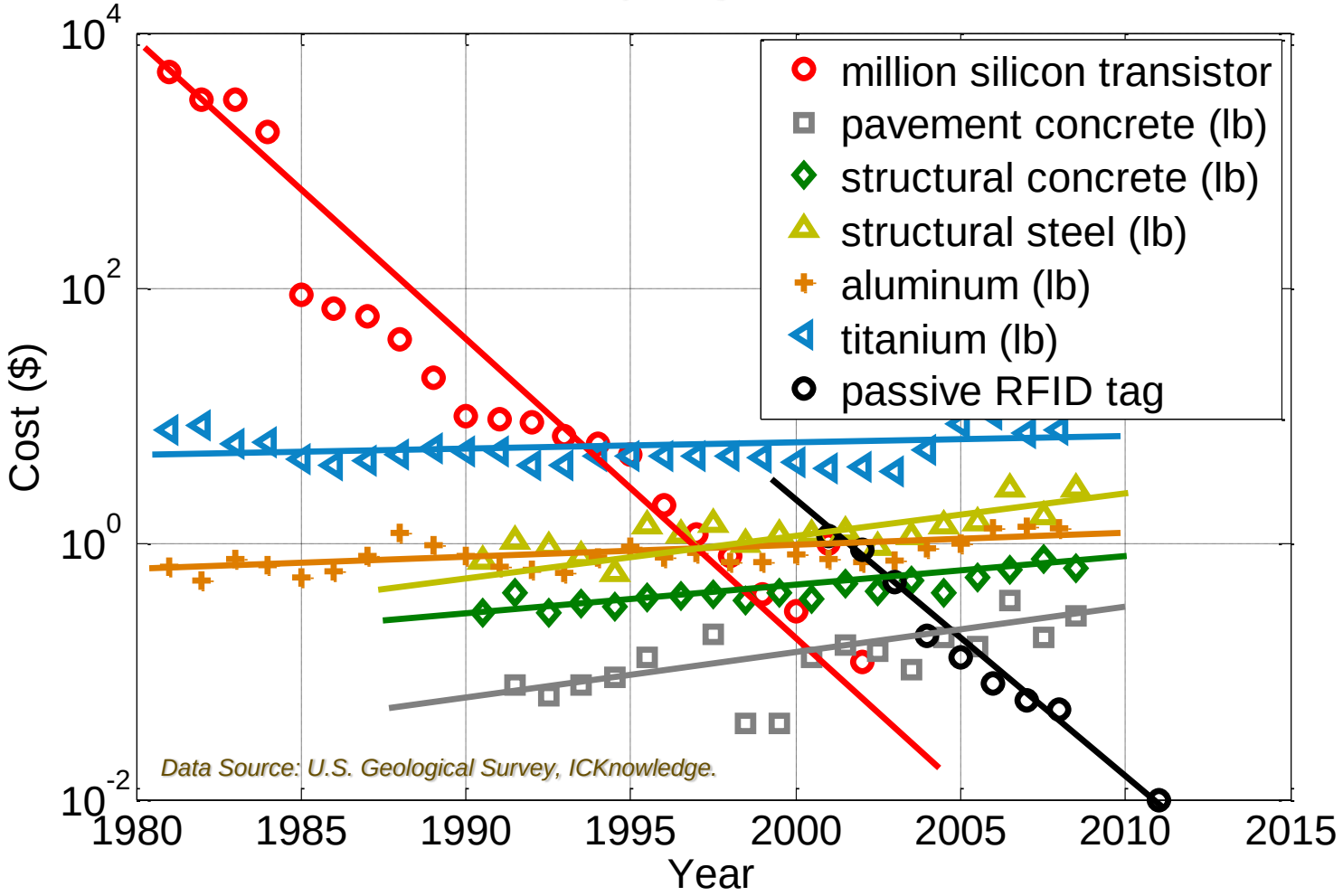
Michigan State University

Moore's Law and Structural Health Monitoring

Chakrabartty, Feng, Aono, SPIE 2013.



- **Economically viable to embed a million transistor IC in every concrete brick, on a pound of titanium alloy, a pound of steel, …**

Sensing Issues in Civil Structural Health Monitoring

- **Cost**
- **Size**
- **Power Source**
- **Maintenance – Maintenance free sensors**
- **Data meaning and interpretation**
- **Ease of installation and use**
- **Data type and format – Integration with existing management systems**
- **Extreme events monitoring**

Two Technologies

Long-term Tagging Technology

Events Detection and Condition Monitoring Technology

Pavement Tagging Technology

PCC Mixture Design Inputs

Cement Content (lbs)
- Type of cement

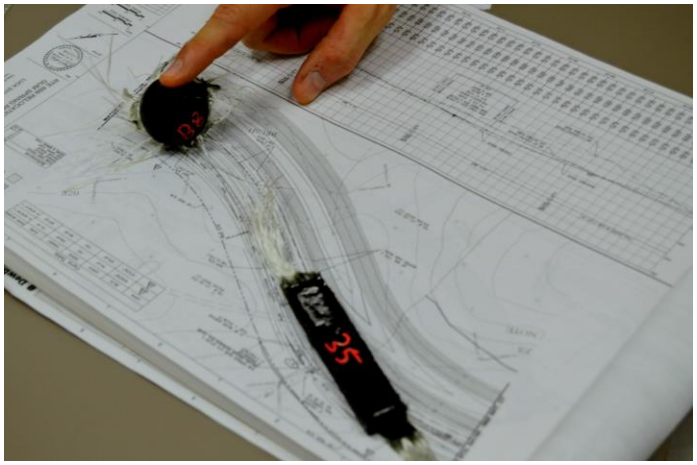
Supplementary Cementitious Materials (lbs)
- Type of SCM

Coarse Aggregate (lbs)
- Aggregate Geology
- Coefficient of thermal expansion

Fine Aggregate (lbs)
- Aggregate Geology

Water (lbs)

Admixture(s) (fl.oz)
- Type of admixture(s)



Pavement Tagging Technology

Fresh Concrete Properties

Slump (inches)

Unit Weight (lb/ft^3)

Concrete Temperature (^{O}F)

Entrained Air (%)

Hardened Concrete Properties

Compressive Strength (psi)

Flexural Strength (psi)

Elastic Modulus (psi)

Measure CTE

Construction

Ambient Temperature at the time of concrete placement (^{O}F)

Relative Humidity at the time of concrete placement (%)

Wind Speed (mph)

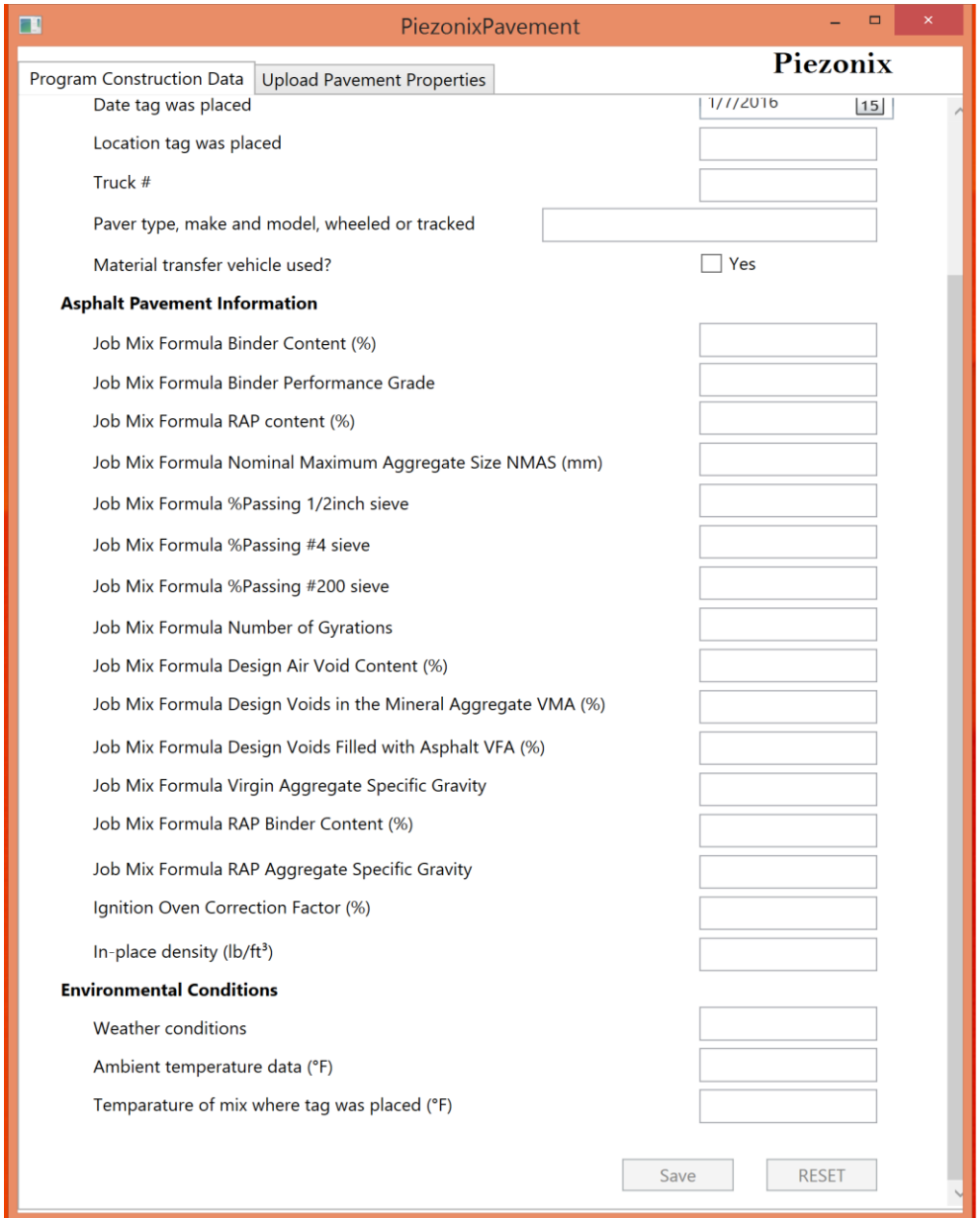
Curing material

Pavement Tagging Technology

Pavement Design

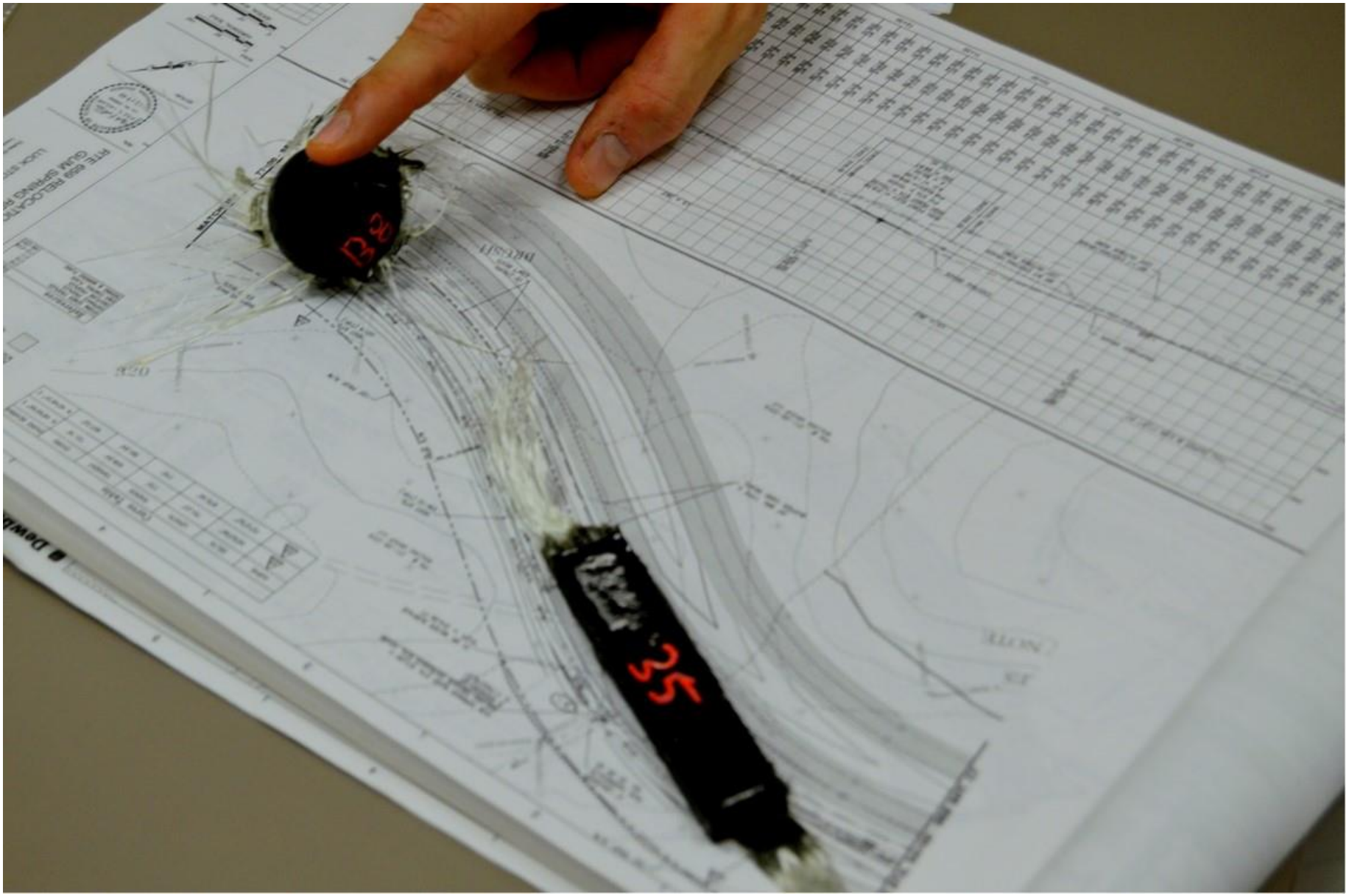
Slab thickness (inches)
Base thickness (inches)
    Base type
Subbase thickness (inches)
    Subbase type
Resilient Modulus of base (psi)
Resilient modulus of subbase (psi)
Modulus of subgrade reaction (psi/in)
    Type of subgrade
Joint spacing
Joint sealant type
Dowel diameter
Dowel spacing
Dowel bar material

Pavement Tagging Technology



Pavement Tagging Technology

Pavement Tagging Technology




HAMM
HD 12


thp

DEMO

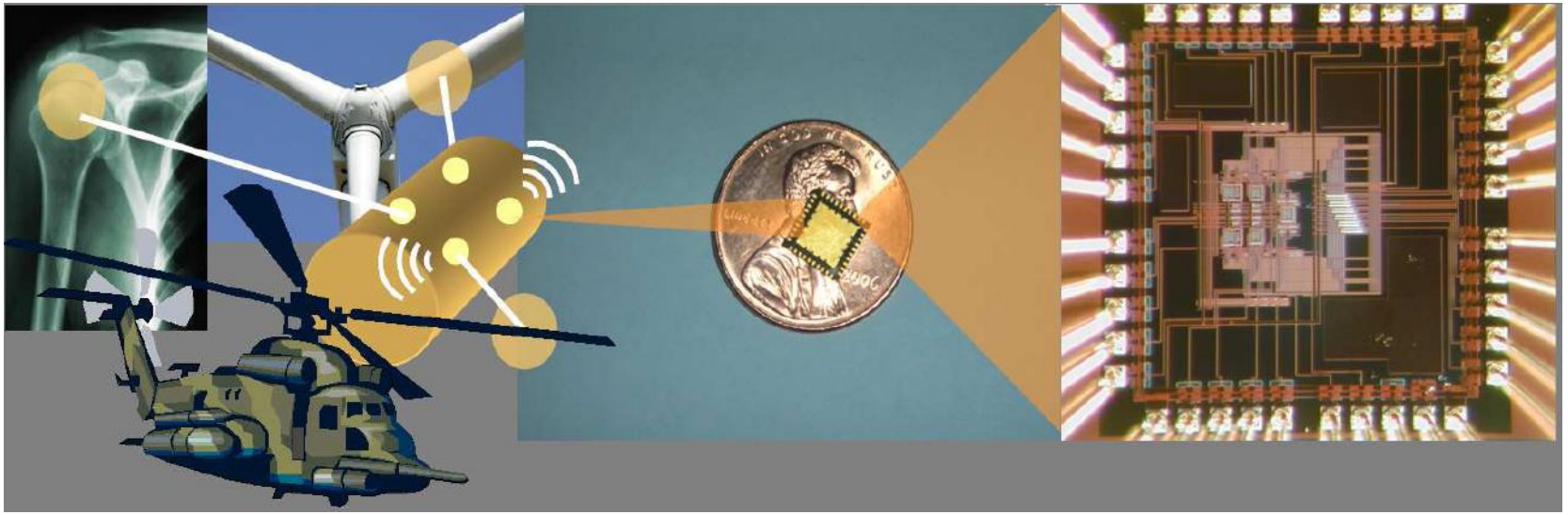
Two Technologies

Long-term Tagging Technology

Events Detection and Condition Monitoring Technology

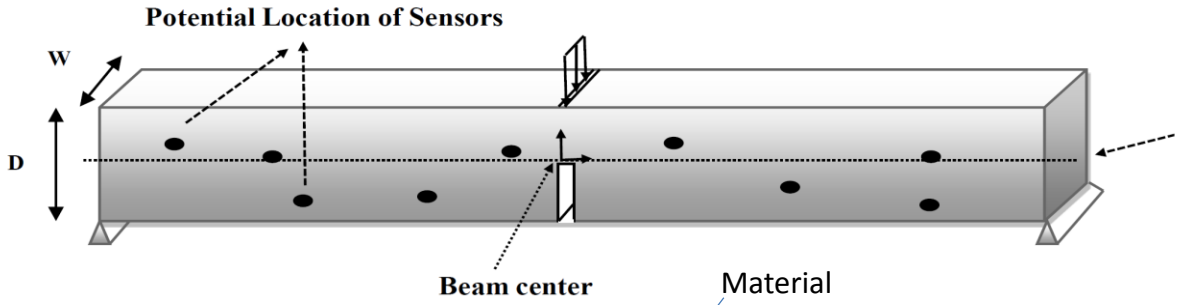
MSU PFG Technology

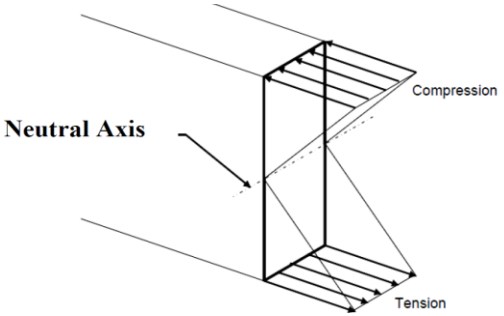
- **Sensors embedded inside "smart structures" that can self-prognosticate damage and mechanical failure.**
- **Zero Maintenance Sensors:** Operational life of sensors comparable to the useful life of the structure – Powering is one of the key challenges.

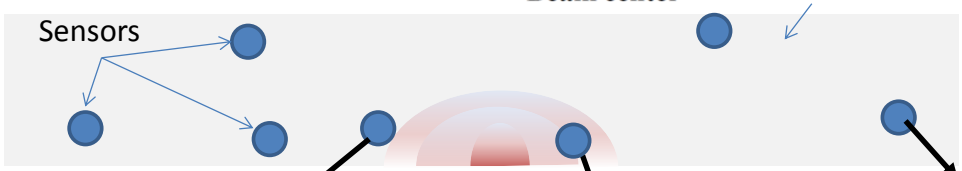


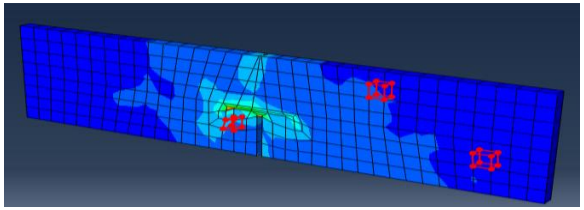
Sensor Size and Powering

Damage

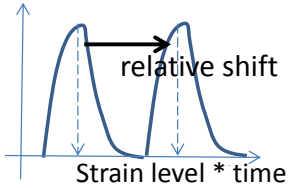




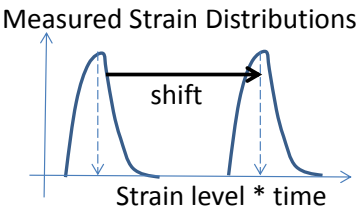




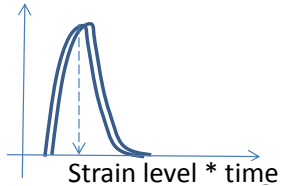
Measured Strain Distributions



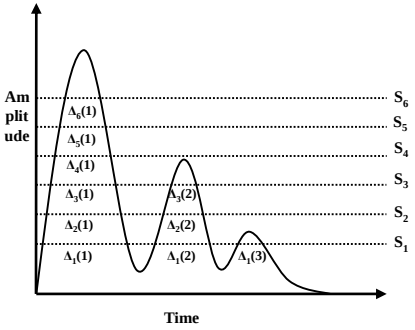
Measured Strain Distributions

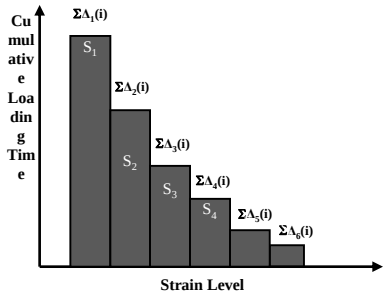


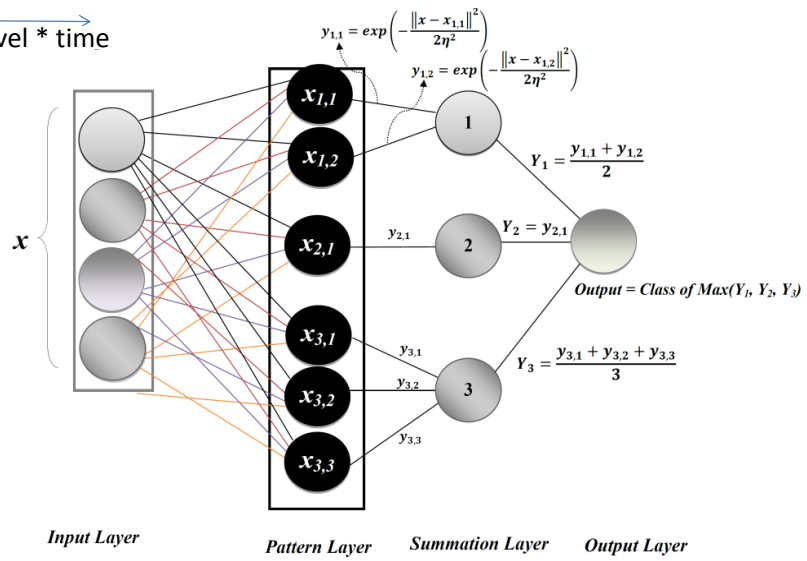
Measured Strain Distributions



Further from damaged area
= less effect = smaller shift





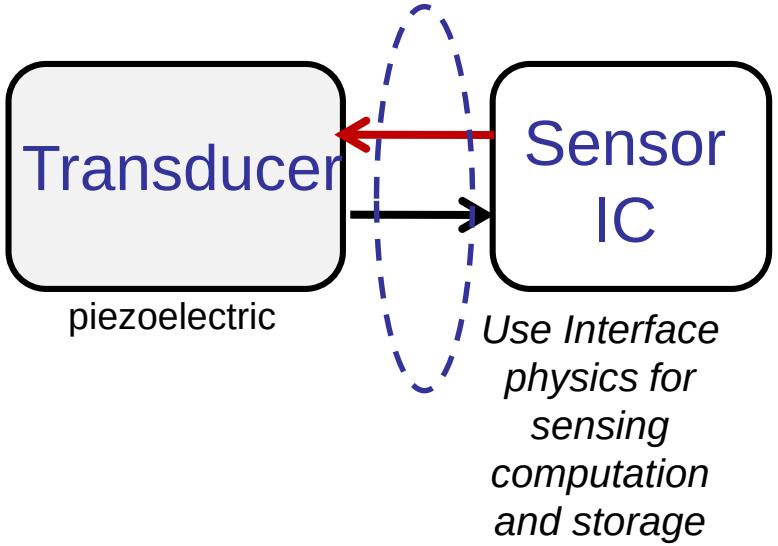


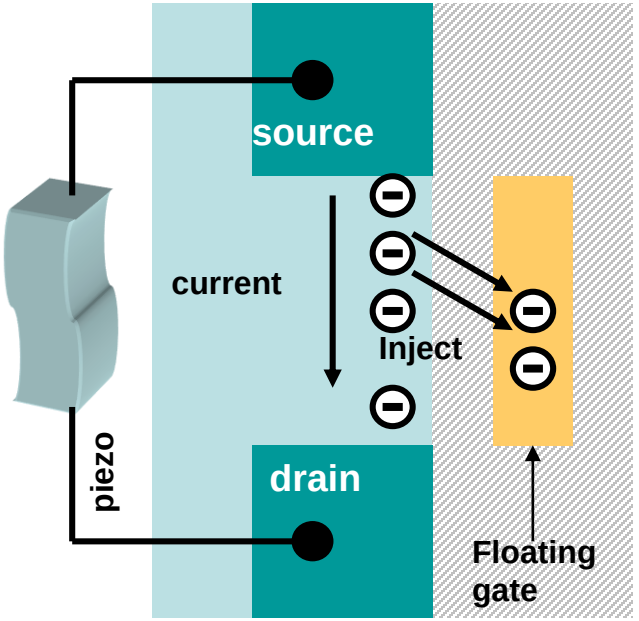
Data compression Protocol

Piezo-floating-gate technology

(US Patents: 7,757,565 and 8,056,420)

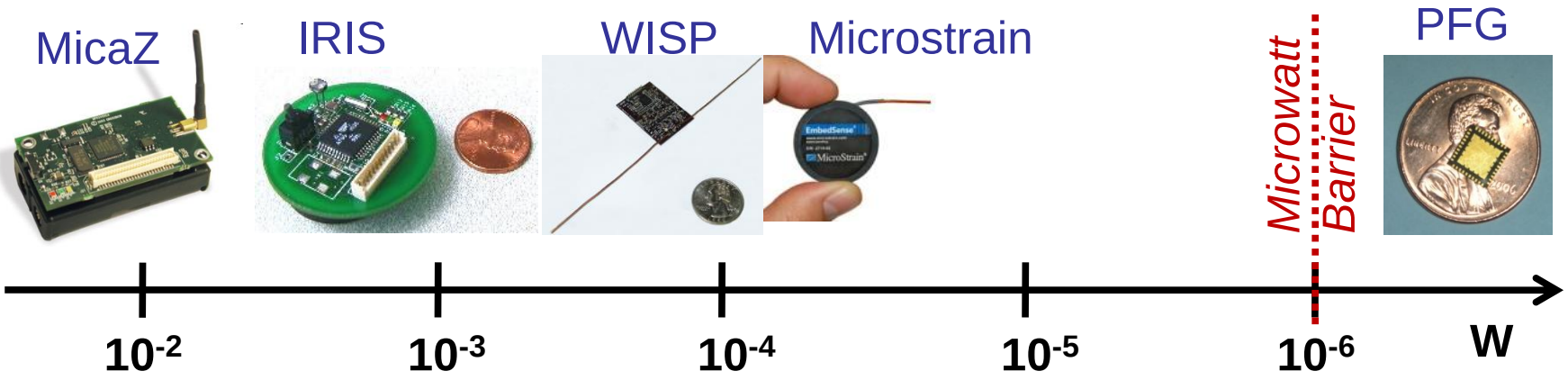
Eliminate power regulators, energy storage, data converters, RAMs and digital signal processors. Use the physics of the device and the structure to perform computation and storage (Use analog computation instead of digital).





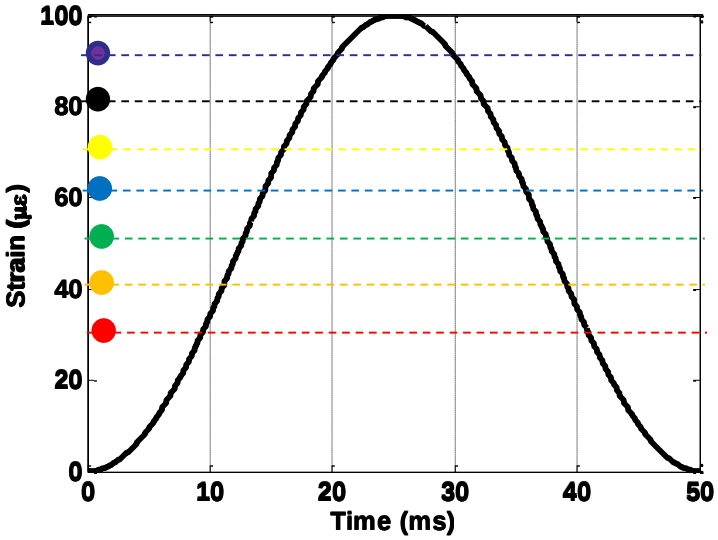
- **Piezoelectric ceramics and polymers can generate high-voltages for low strain-levels but at ultra-low-driving currents.**

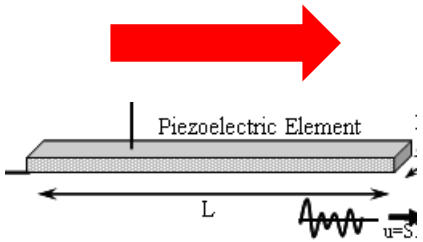
Comparison with other technologies

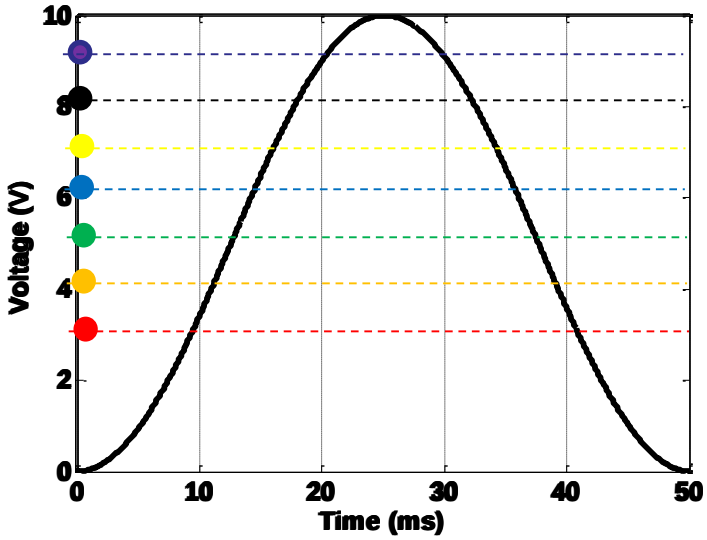


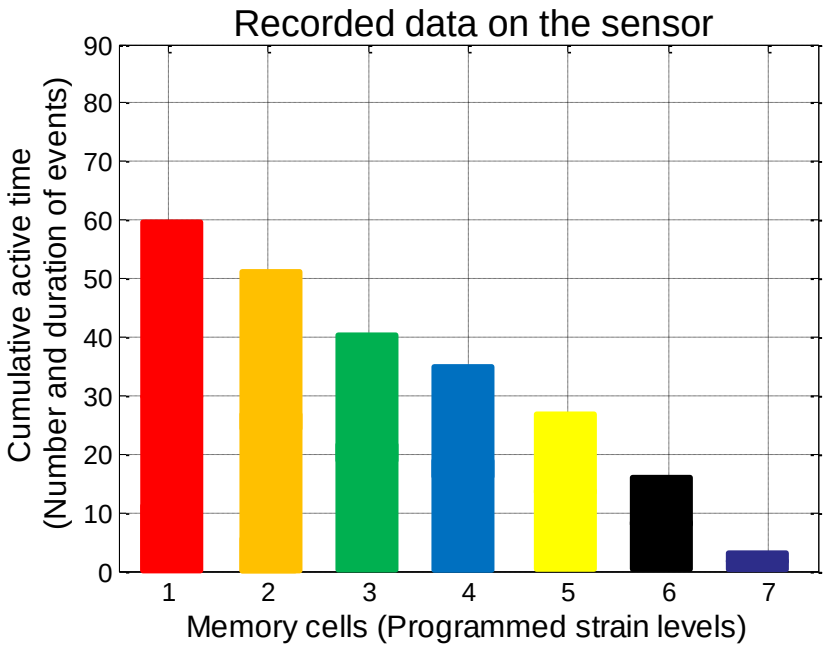
Process	0.5-μm standard CMOS
Size	1900μm x 1500μm
Maximum Current consumption	110nA (7-channel level crossing monitoring)
	90nA (3-channel impact monitoring)

Data Recording Protocol on the sensor

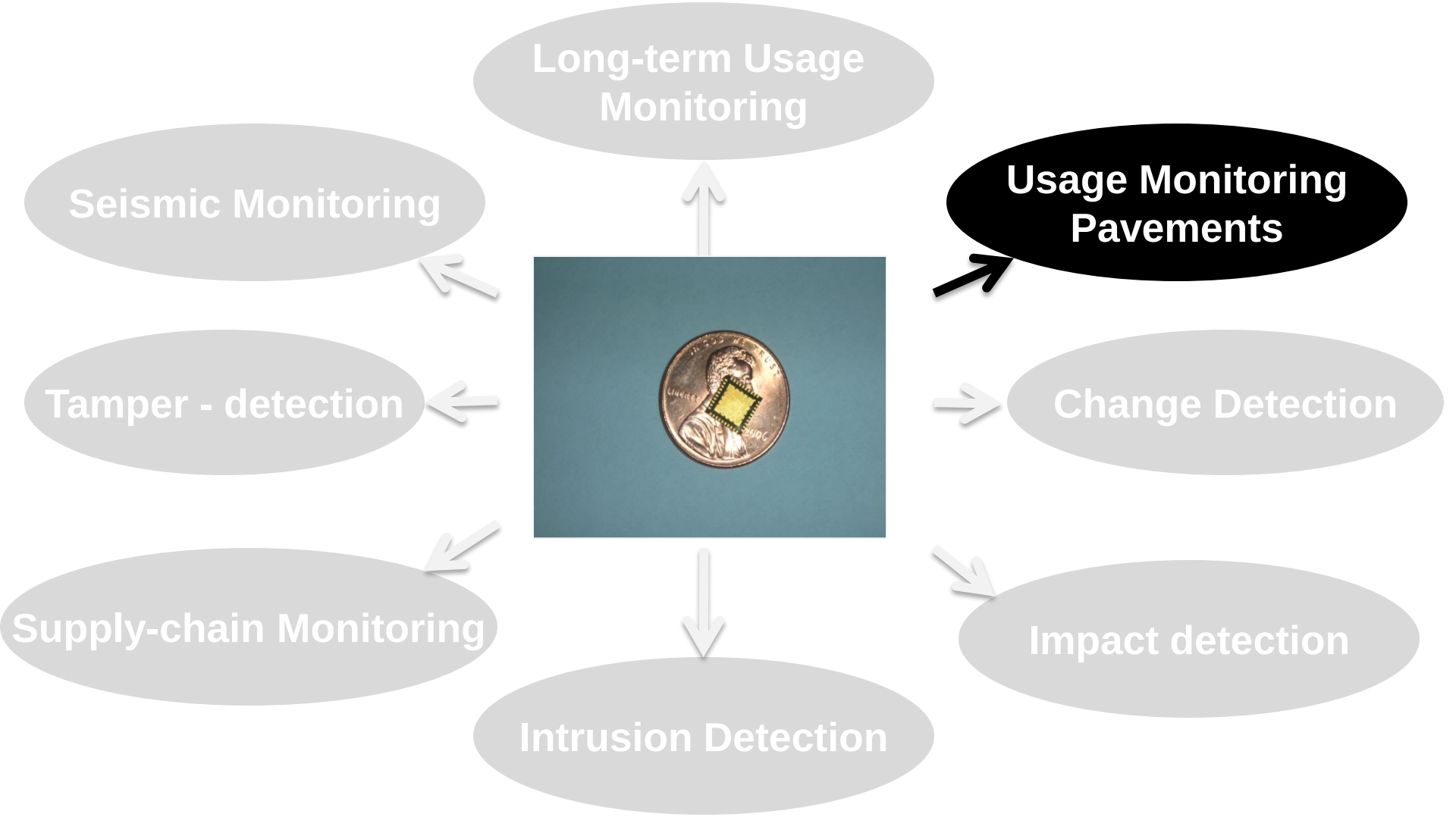








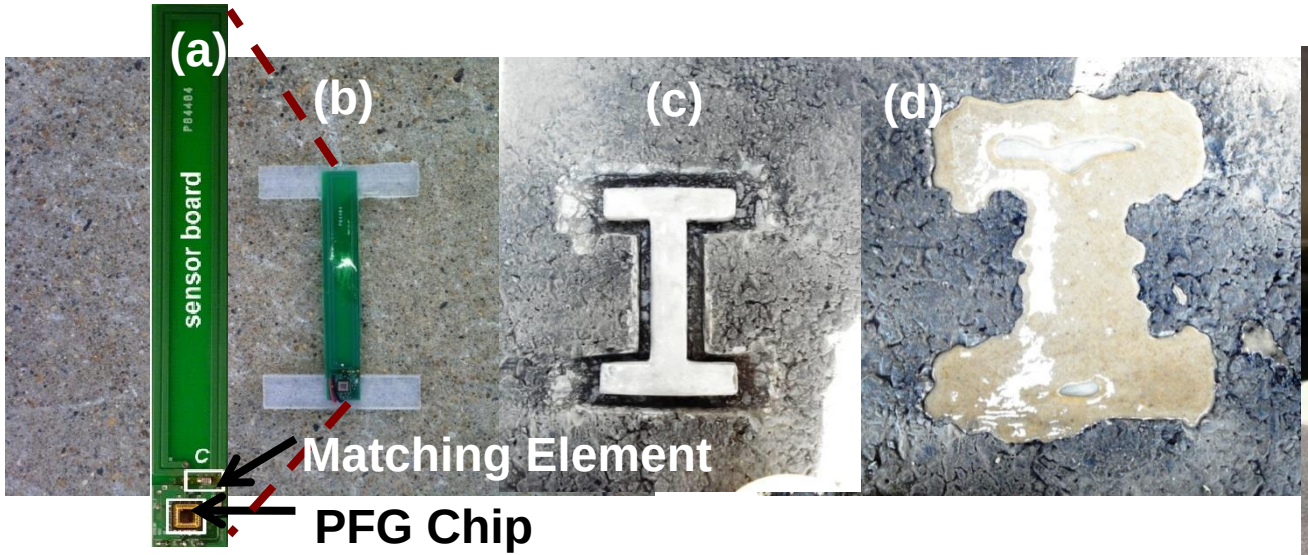
Road-map: One sensor multiple Modalities

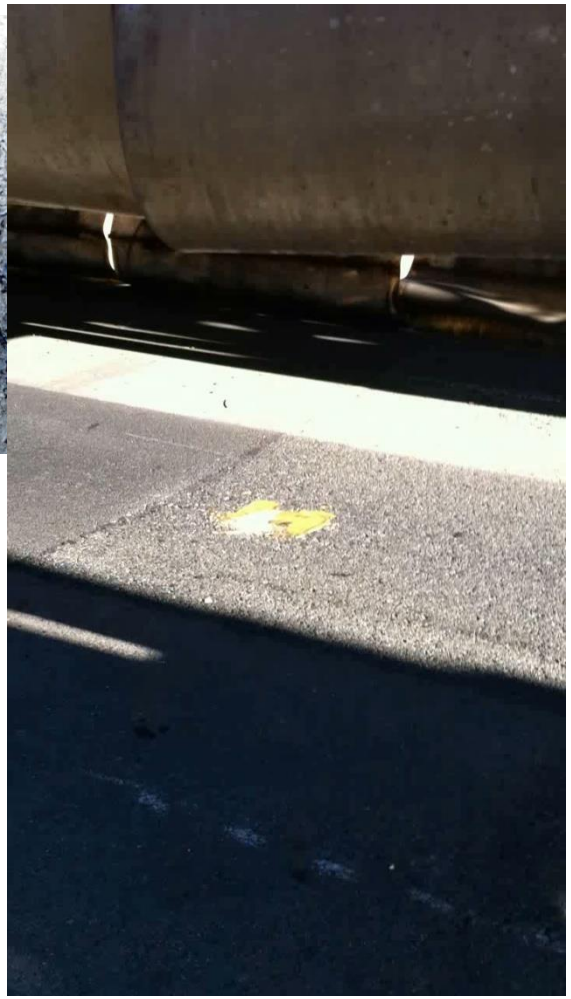


Challenges:

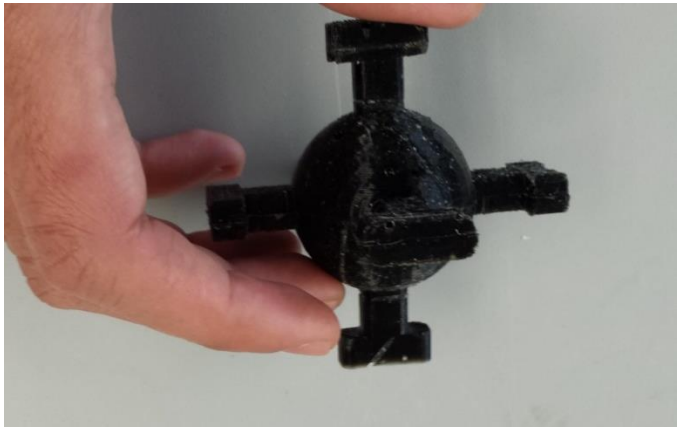
- Size
- Attachment to the host structure
- Location
- Meaning of data
- Data interpretation and prognosis methods

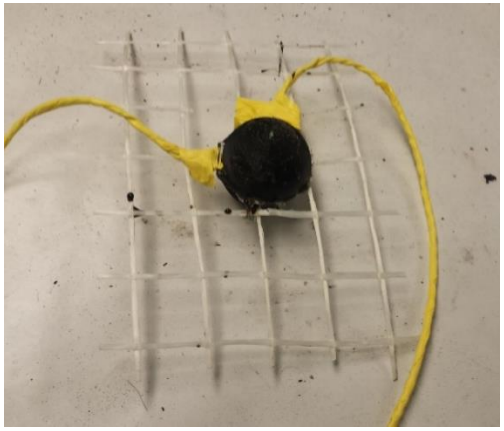
Pavement Monitoring System



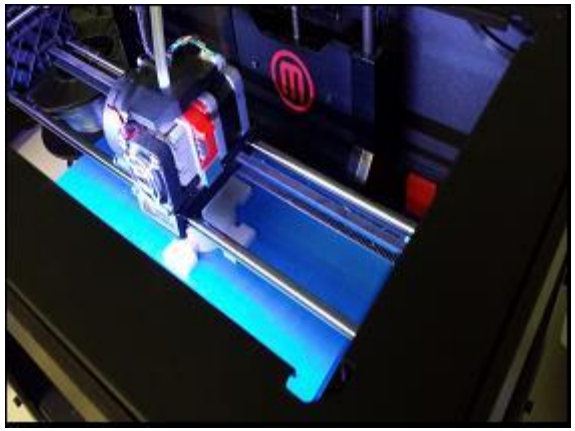


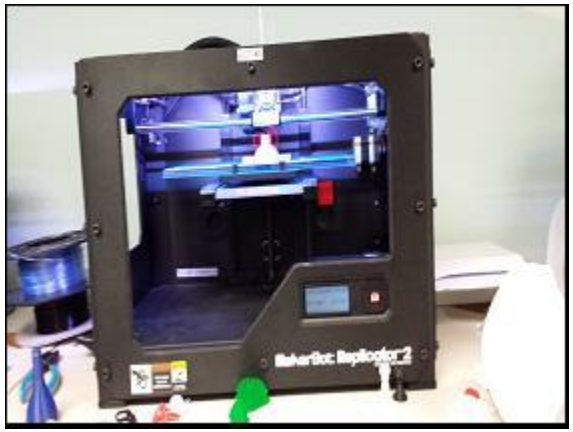
- At Turner-Fairbanks Highway Research Facility.

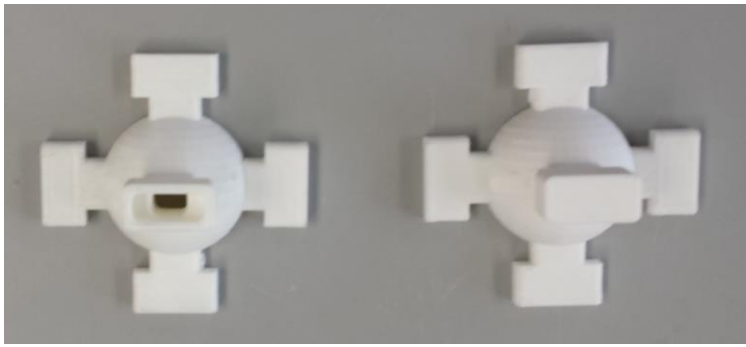


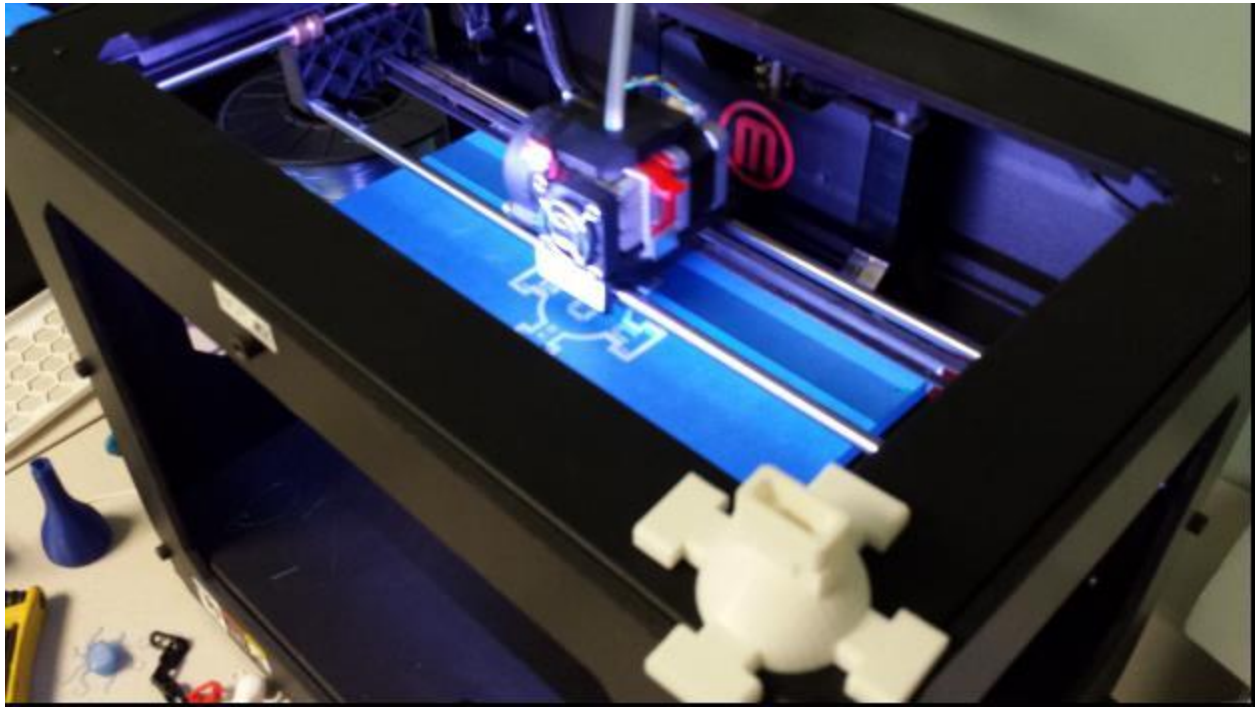


Manufacturing

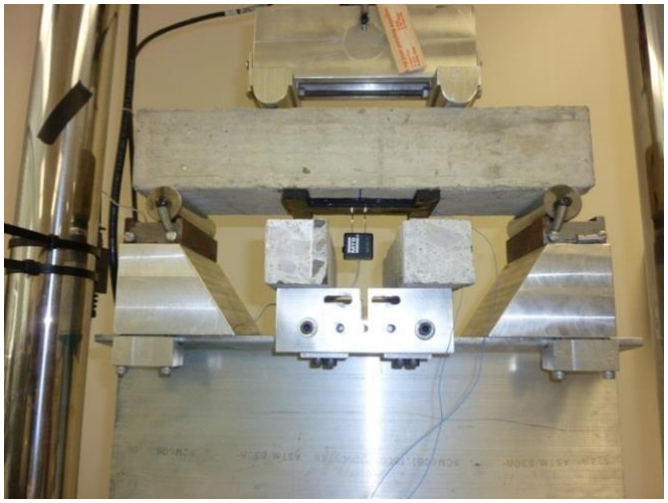


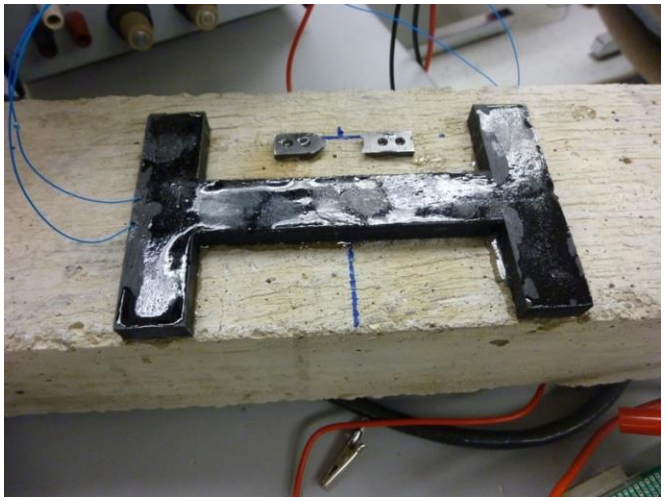


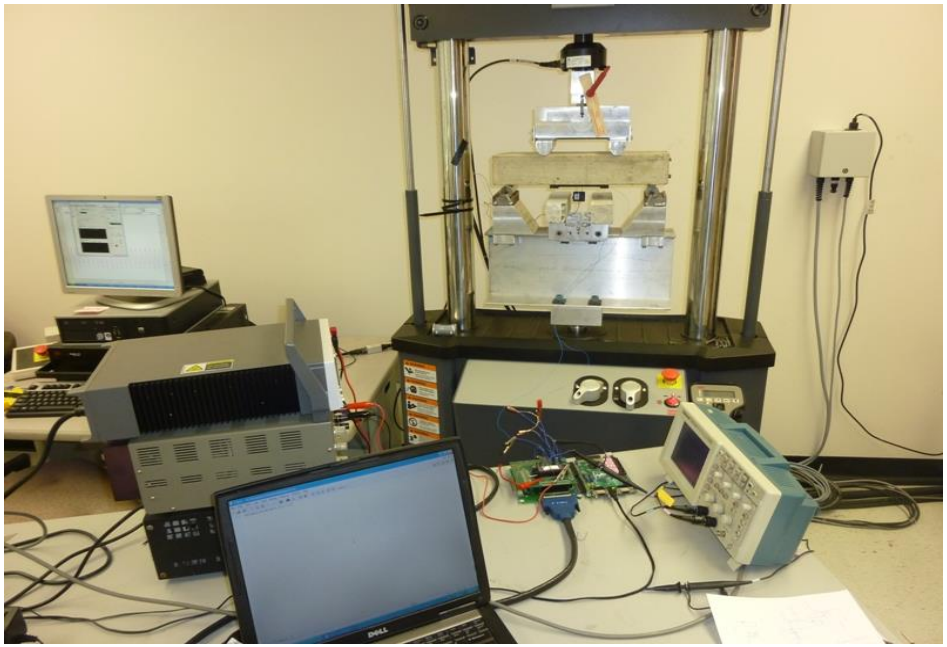




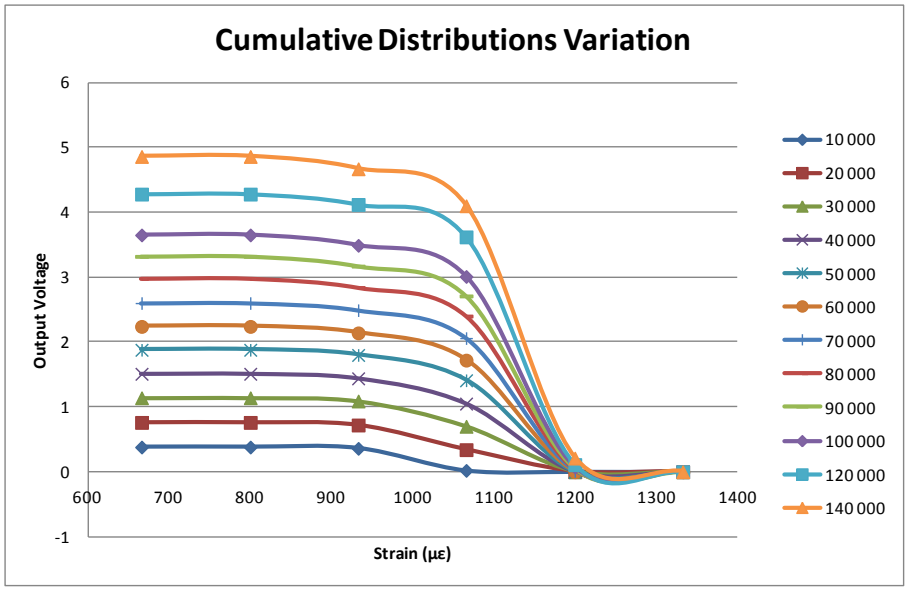
Data Interpretation - Damage

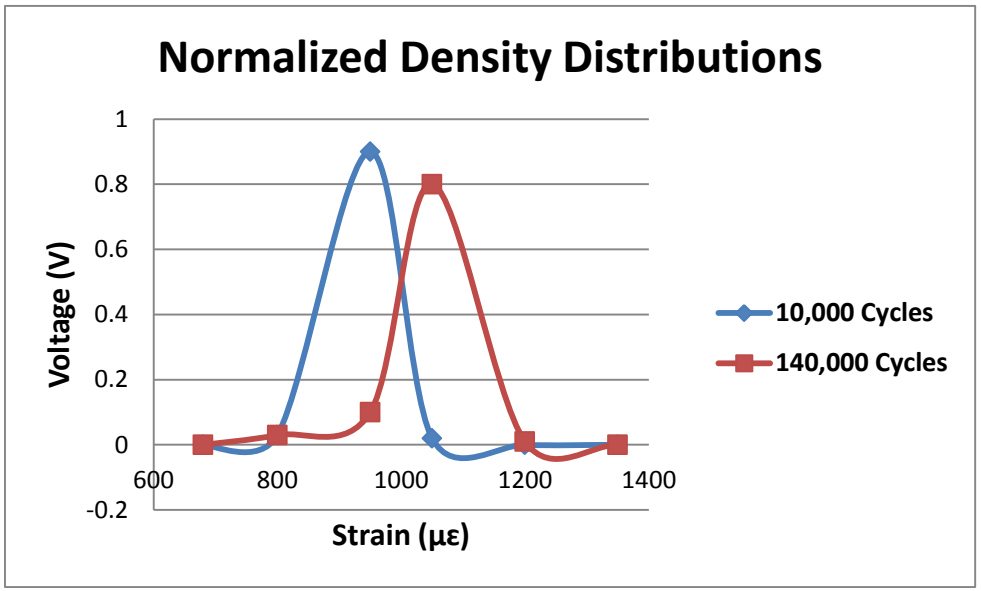


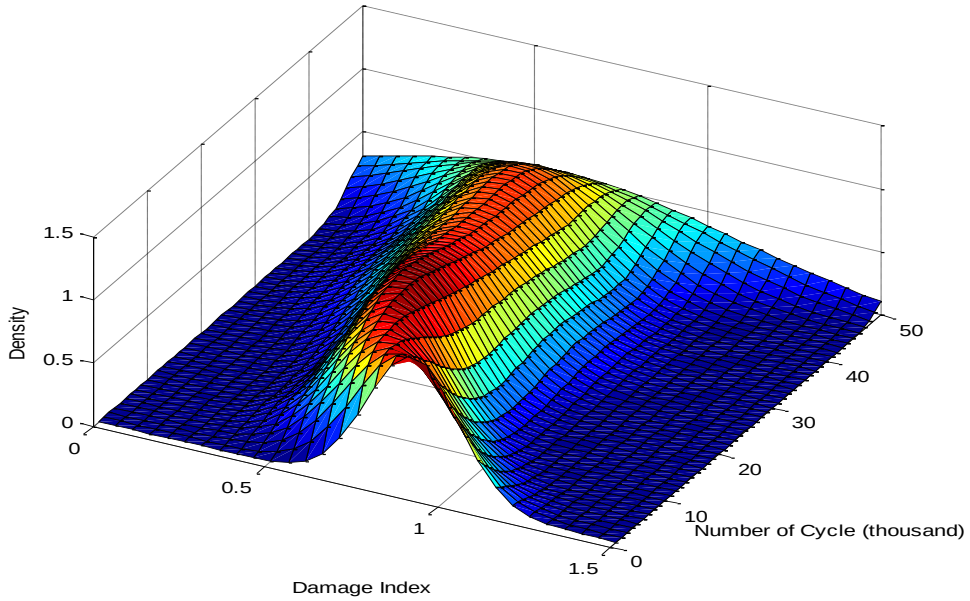




Data Interpretation - Damage

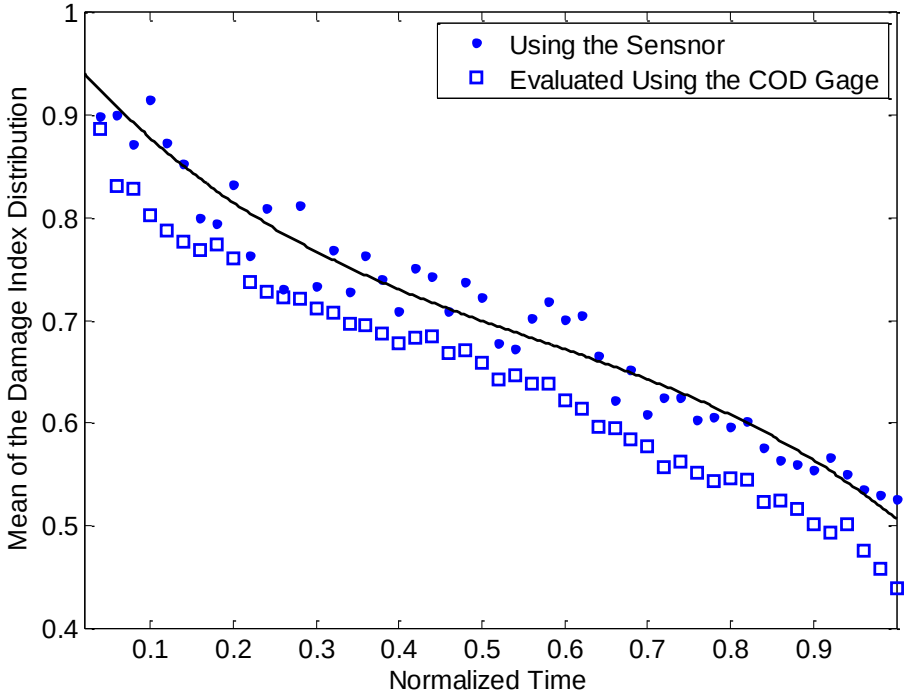




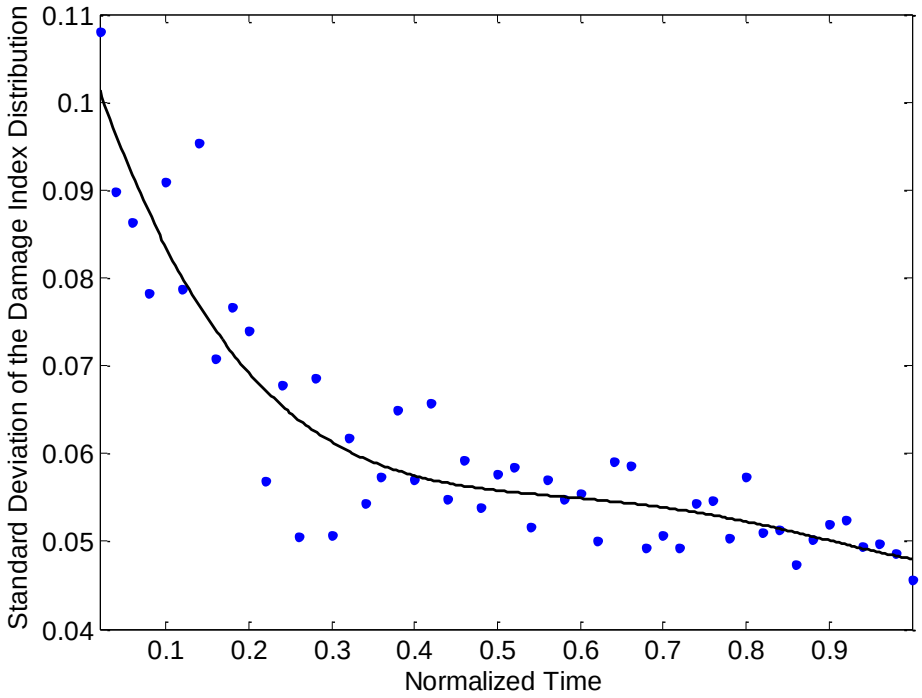


Probability distribution of the damage index versus the number of cyclic loading events.

Data Interpretation - Damage



Example - Variation over time of the mean damage index (from sensor) versus the damage index evaluated using data from a COD gage.



Example - Variation over time of the standard deviation of the damage index distribution.

Actual remaining life	Predicted remaining life using the sensor
391	325
420	425
9350	7125
7022	11048
10980	23011

Predictions for example specimens

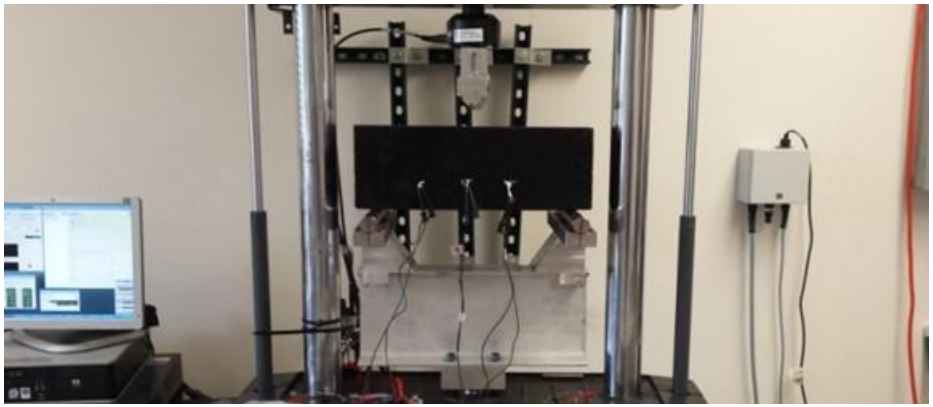
Asphalt concrete sample:

Length: 18″ (457.2 mm)
Span length: 15″ (381 mm)
Thickness: 6.5″ (165.1 mm)
Width: 6″ (152.4 mm)

- Damage states:

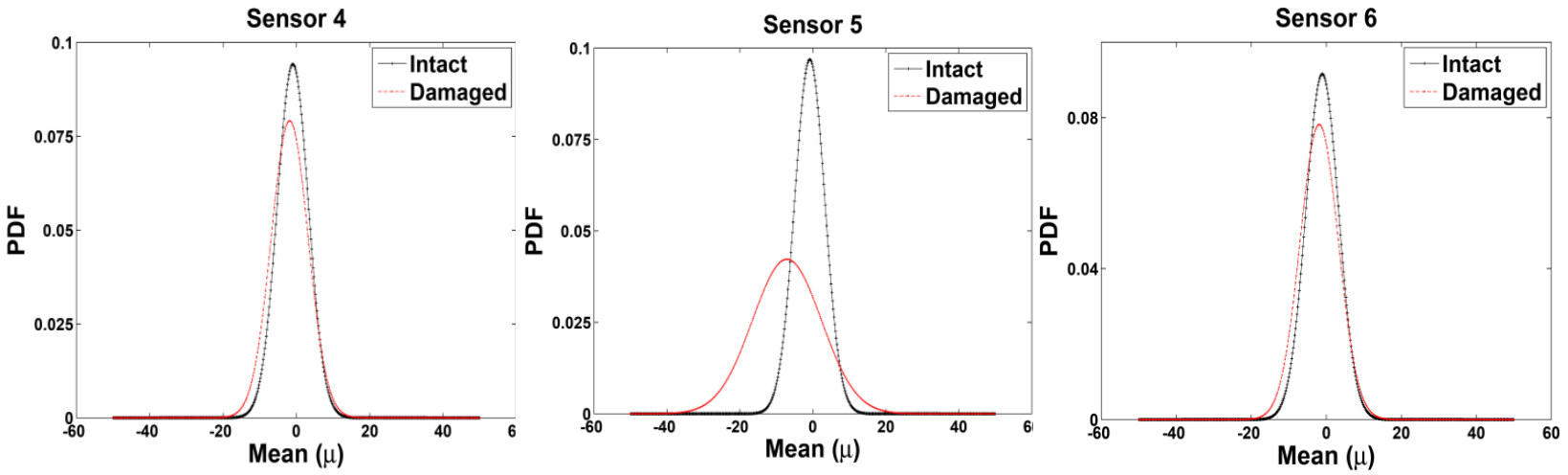
Intact: a= 0 mm
Damage 1: a = 7/8'' (22.2 mm)
Damage 2: a = 1 1/4'' (31.75 mm)
Damage 3 (crack propagation): a = 1 3/4'' (44.45 mm)

Single Edge Notched Beam Test

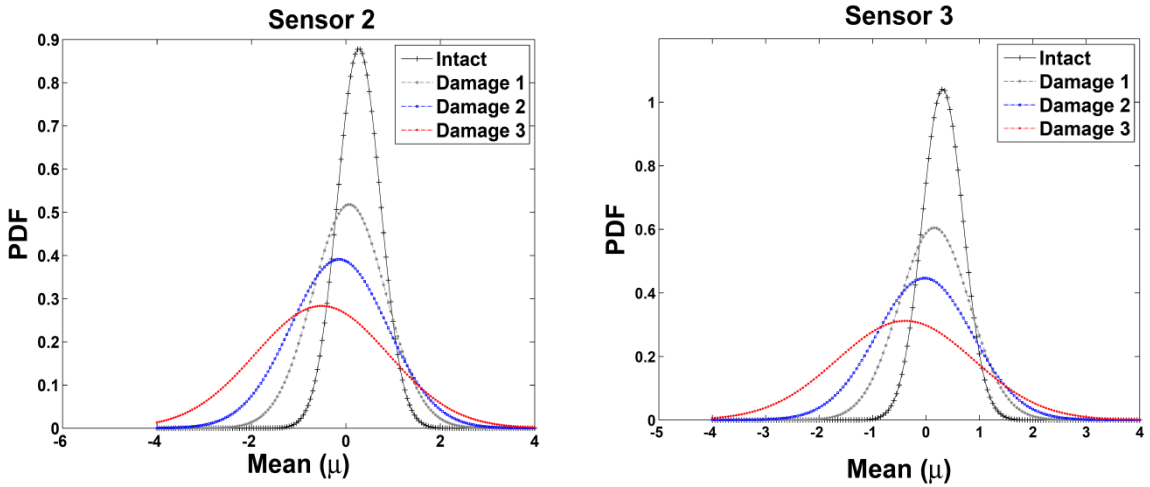


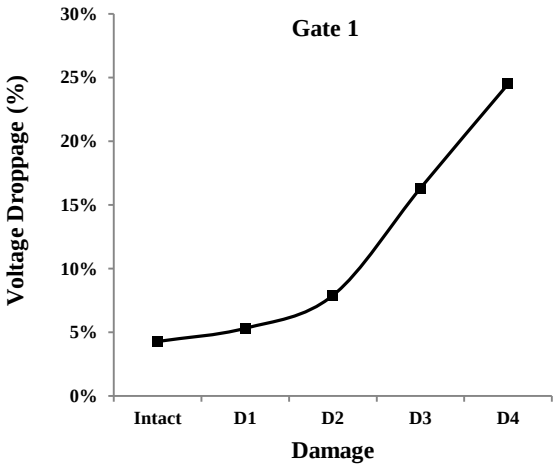
The crack propagation phase during the test

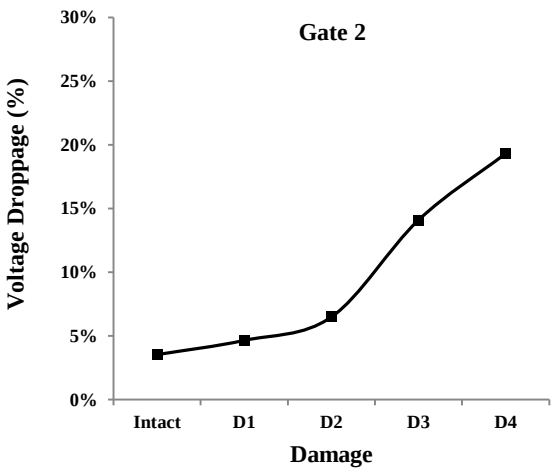
Damage Detection Based on the FE Results

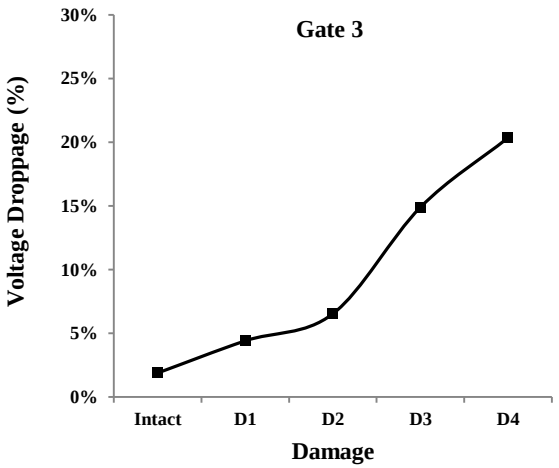


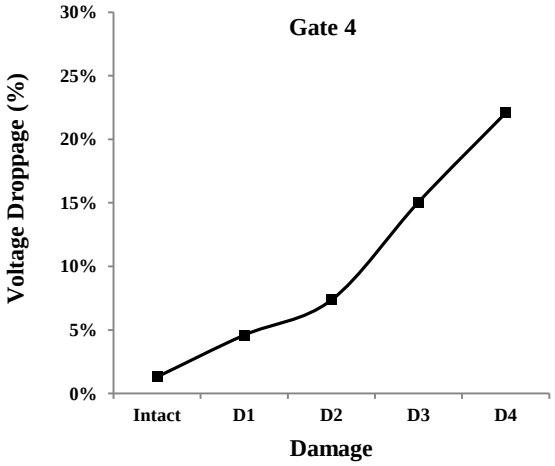
Damage Detection Based on the Experimental Results (0.2 mm, 5 Hz)

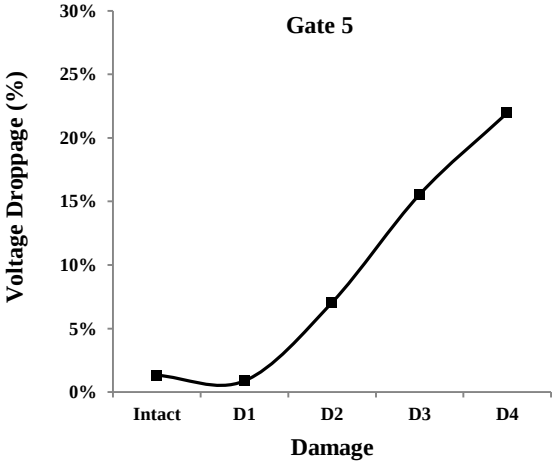


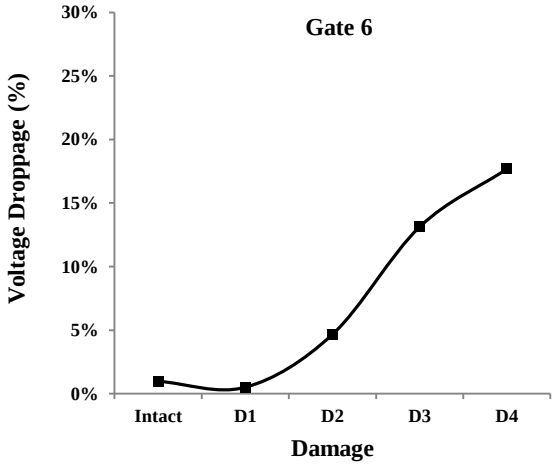

Gate 1
Voltage Droppage (%)
30%
25%
20%
15%
10%
5%
0%
Intact
D1
D2
D3
D4
Damage


Gate 2
Voltage Droppage (%)
30%
25%
20%
15%
10%
5%
0%
Intact
D1
D2
D3
D4
Damage


Gate 3
Voltage Droppage (%)
30%
25%
20%
15%
10%
5%
0%
Intact
D1
D2
D3
D4
Damage

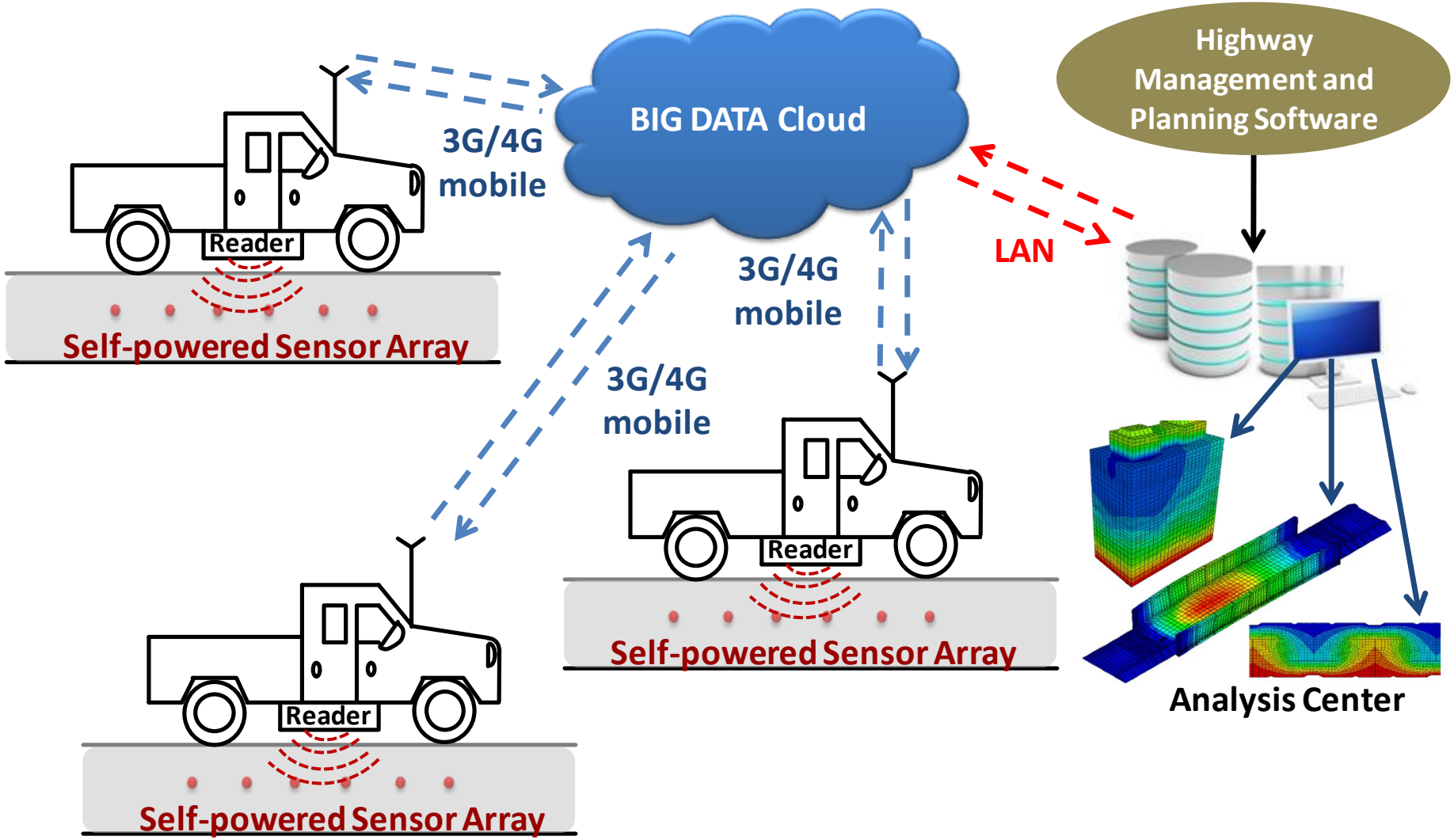

Gate 4
Voltage Droppage (%)
30%
25%
20%
15%
10%
5%
0%
Intact
D1
D2
D3
D4
Damage


Gate 5
Voltage Droppage (%)
30%
25%
20%
15%
10%
5%
0%
Intact
D1
D2
D3
D4
Damage


Gate 6
Voltage Droppage (%)
30%
25%
20%
15%
10%
5%
0%
Intact
D1
D2
D3
D4
Damage

Looking into the Future

- Internet-of-Things and Big Data Integration.
- **Vehicle-to-Infrastructure Communication**



MICHIGAN STATE UNIVERSITY

CIVIL & ENVIRONMENTAL ENGINEERING

Smart Sensing Technology for Infrastructure Monitoring

Supported by FHWA and USDOT

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