Smart Sensing Technology for Infrastructure Monitoring

Supported by FHWA and USDOT

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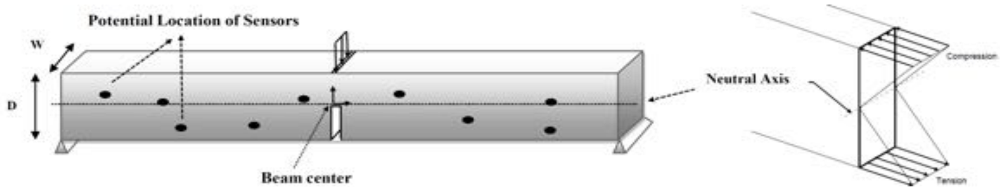
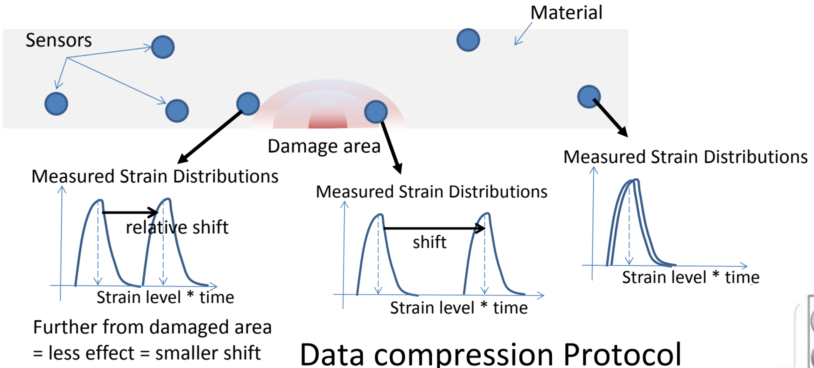
8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements

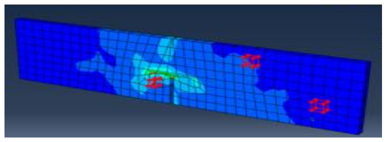
Two Technologies

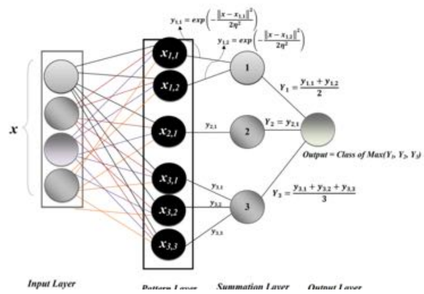
- Long-term Tagging Technology
- Events Detection and Condition Monitoring Technology

Damage

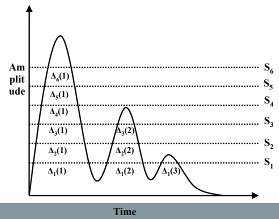


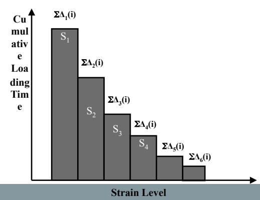




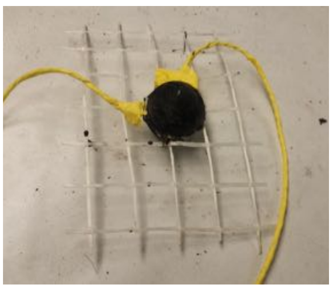


Data compression Protocol





8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements (MCD2016)



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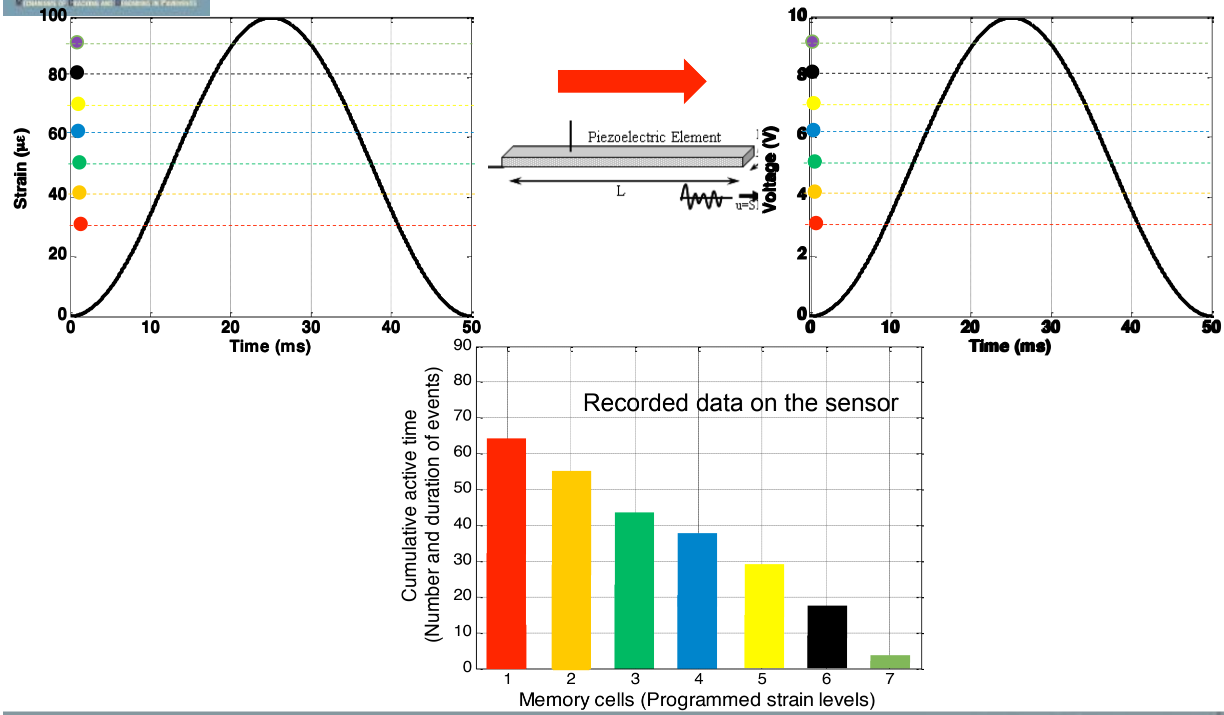
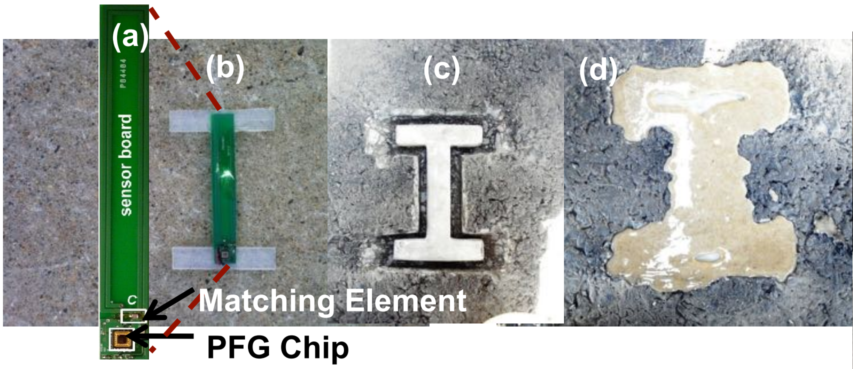
Data Recording Protocol on the sensor



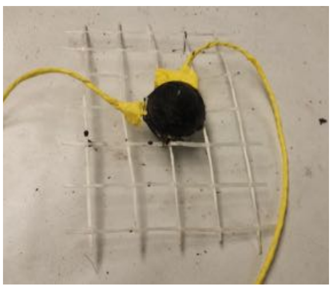
Challenges:

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

Pavement Monitoring System



- At Turner-Fairbanks Highway Research Facility.



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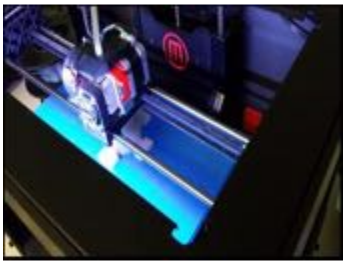
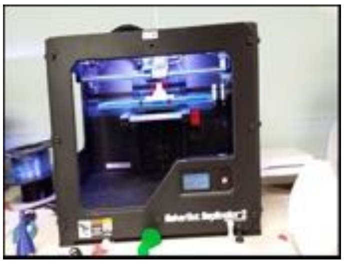
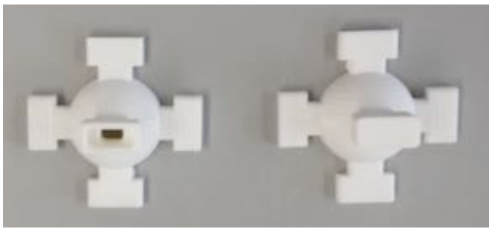
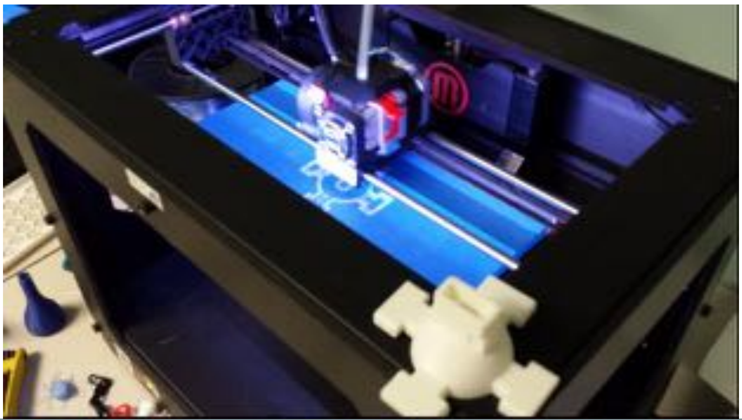
Manufacturing

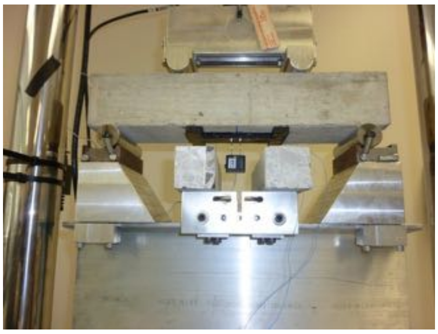


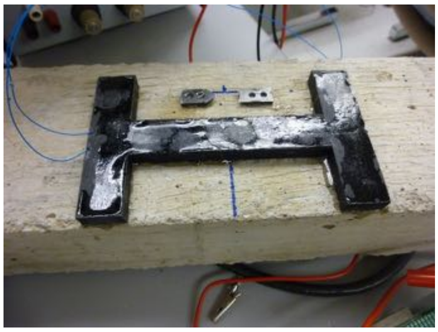


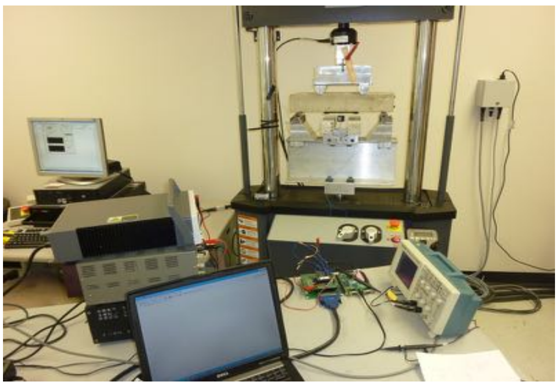




Data Interpretation - Damage







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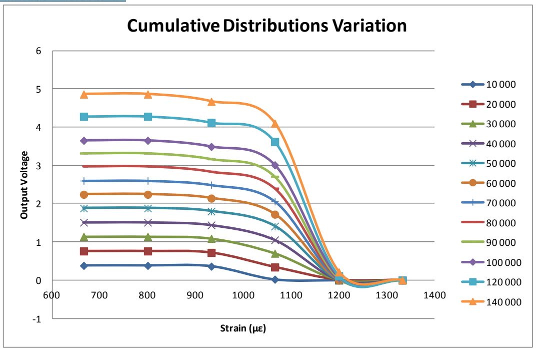
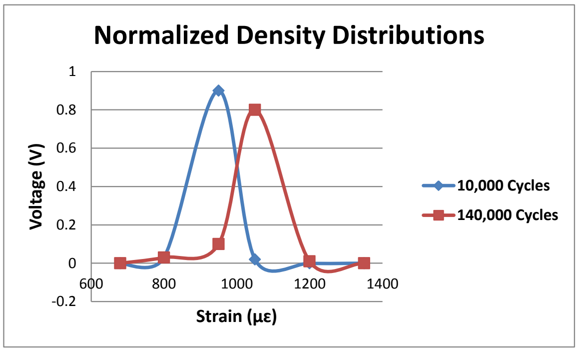
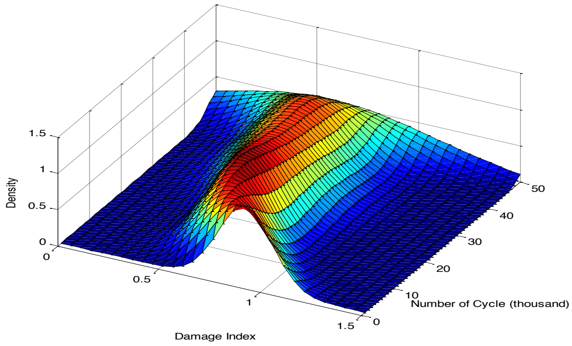
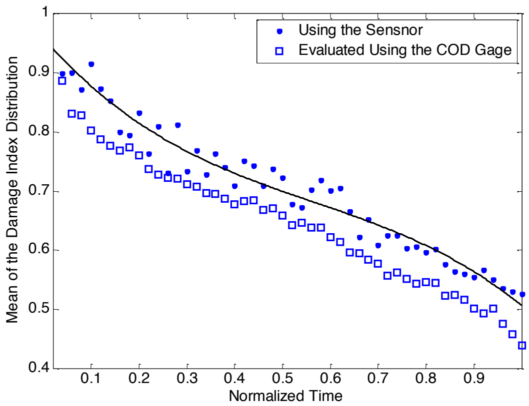




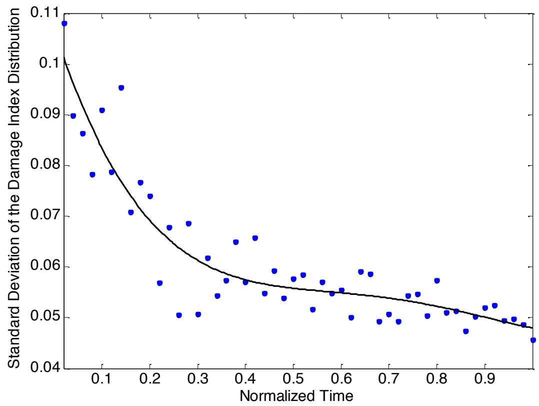


Probability distribution of the damage index versus the number of cyclic loading events.

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

Asphalt concrete sample:

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

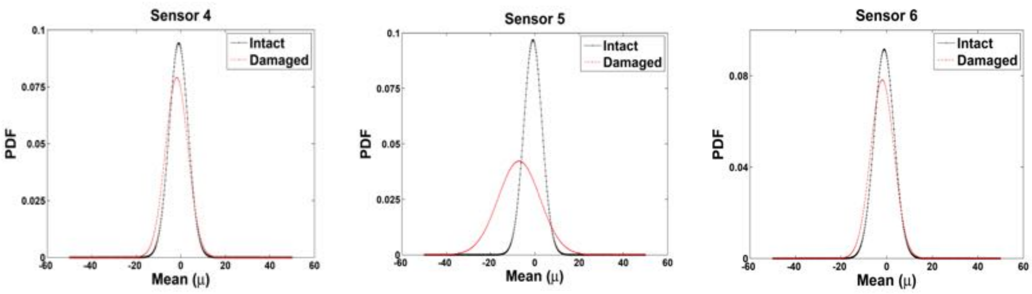
- Damage states:

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)

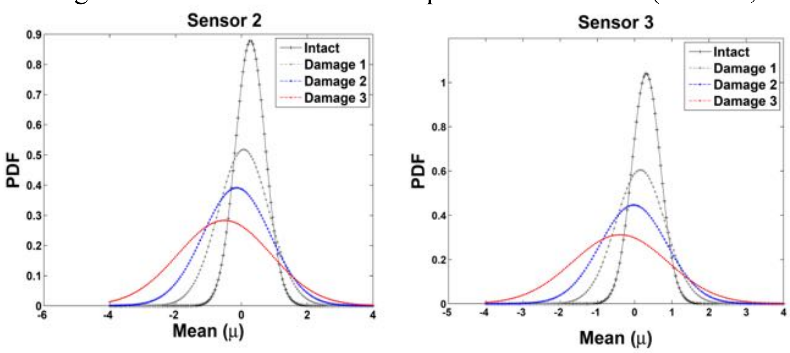
Single Edge Notched Beam Test

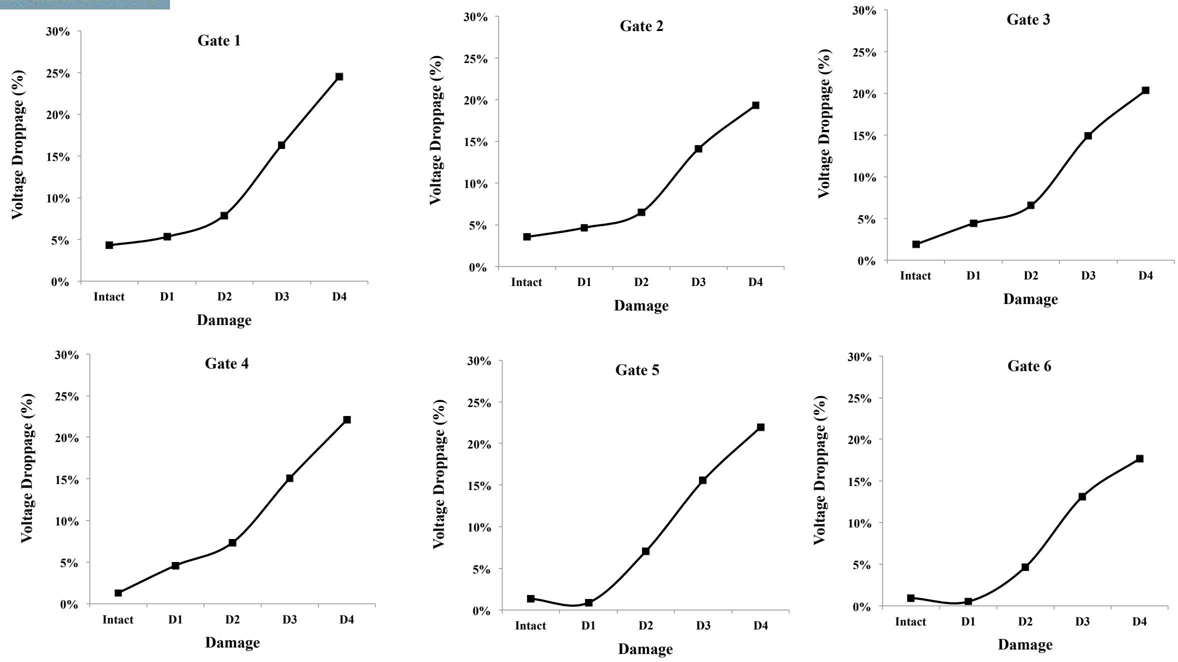
The crack propagation phase during the test

Damage Detection Based on the FE Results



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

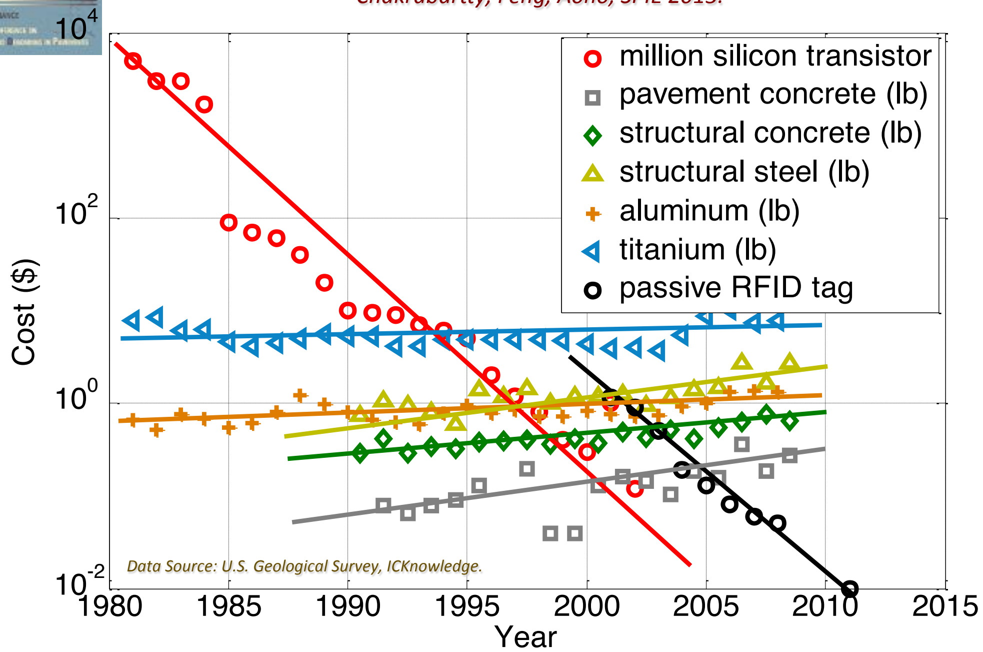




Smart Sensing Technology for Infrastructure Monitoring

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**

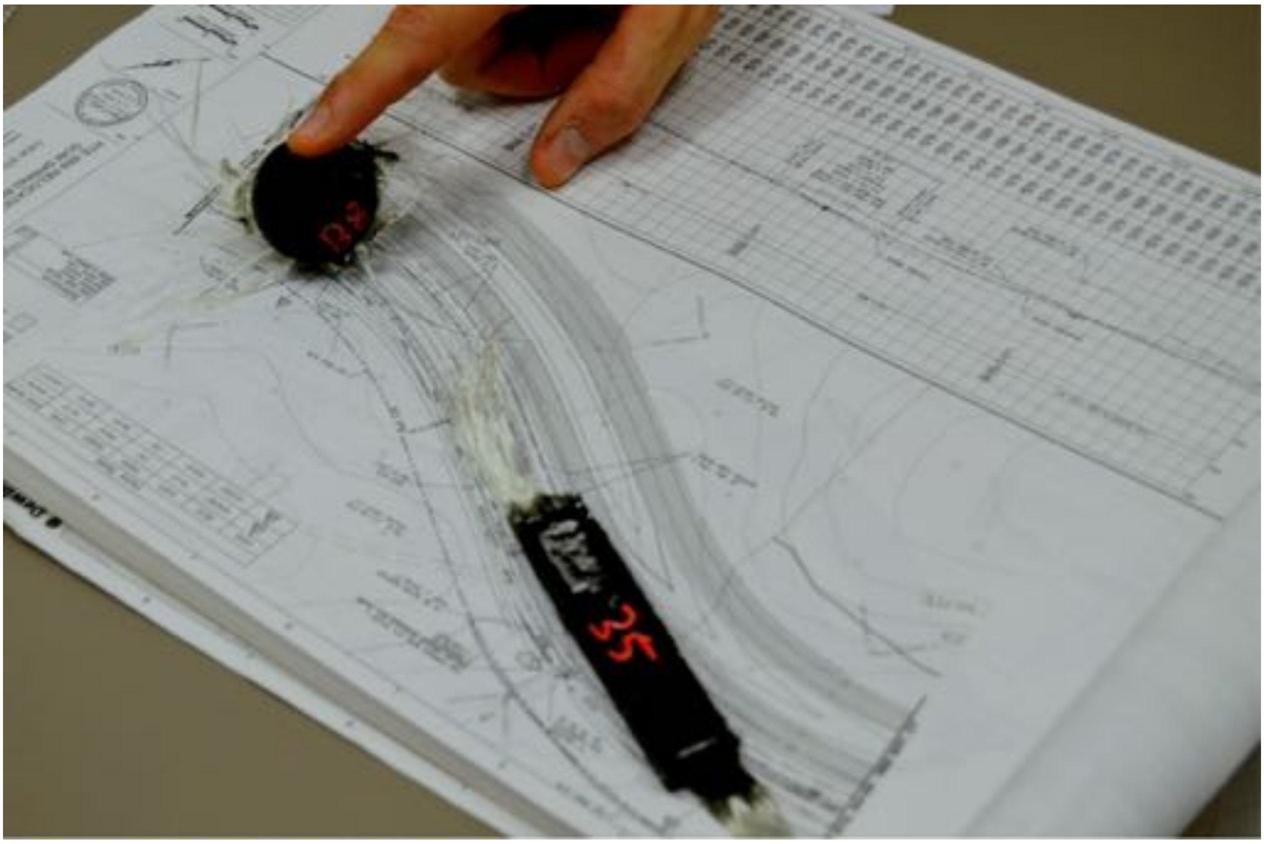
Sensing Issues in Civil Structural Health Monitoring

- **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



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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

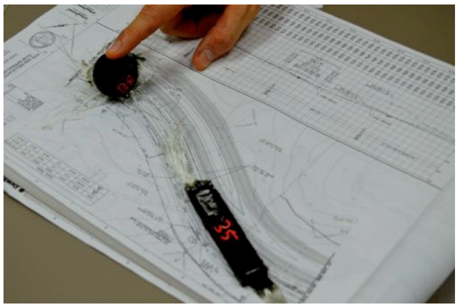
Fine Aggregate (lbs)

- 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

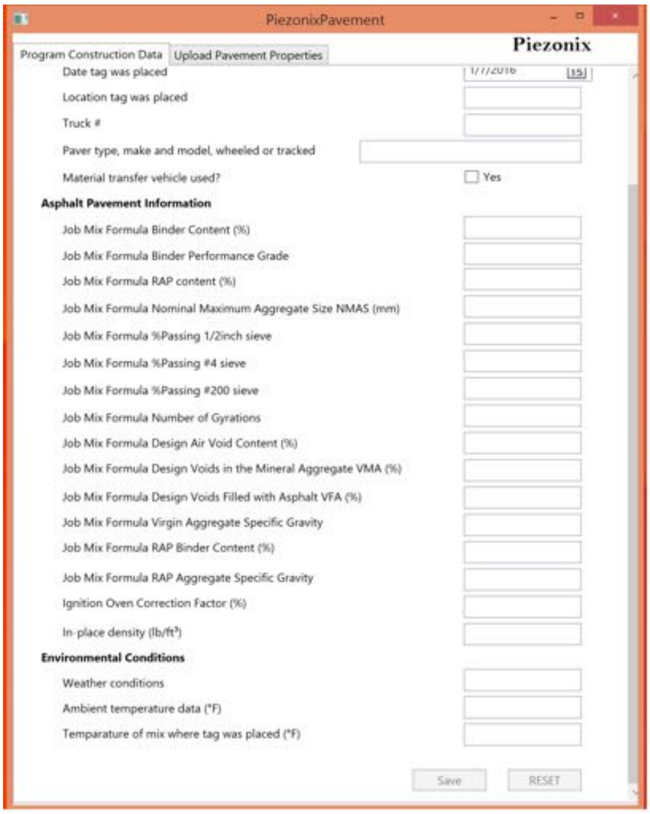
Joint sealant type

Dowel diameter

Dowel spacing

Dowel bar material

Pavement Tagging Technology


PiezonixPavement

Piezonix

Program Construction Data | Upload Pavement Properties

Date tag was placed 1/7/2016

Location tag was placed

Truck #

Paver type, make and model, wheeled or tracked

Material transfer vehicle used? ☐ Yes

Asphalt Pavement Information

Job Mix Formula Binder Content (%)

Job Mix Formula Binder Performance Grade

Job Mix Formula RAP content (%)

Job Mix Formula Nominal Maximum Aggregate Size NMAS (mm)

Job Mix Formula %Passing 1/2inch sieve

Job Mix Formula %Passing #4 sieve

Job Mix Formula %Passing #200 sieve

Job Mix Formula Number of Gyrations

Job Mix Formula Design Air Void Content (%)

Job Mix Formula Design Voids in the Mineral Aggregate VMA (%)

Job Mix Formula Design Voids Filled with Asphalt VFA (%)

Job Mix Formula Virgin Aggregate Specific Gravity

Job Mix Formula RAP Binder Content (%)

Job Mix Formula RAP Aggregate Specific Gravity

Ignition Oven Correction Factor (%)

In-place density (lb/ft³)

Environmental Conditions

Weather conditions

Ambient temperature data (°F)

Temparature of mix where tag was placed (°F)

Save RESET

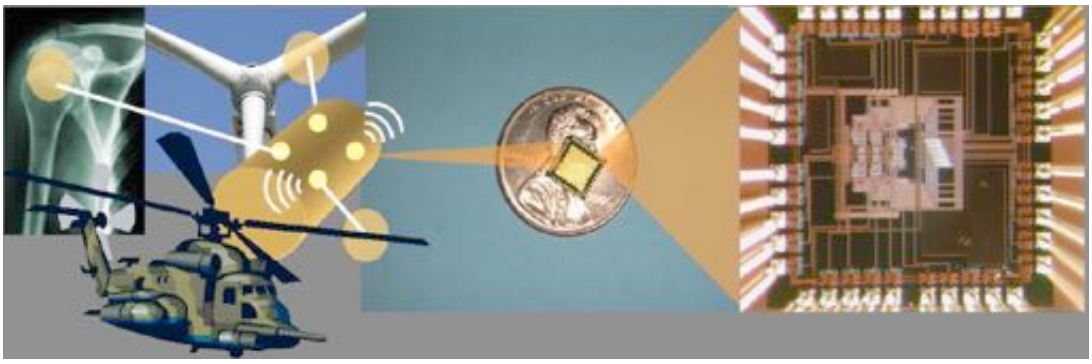
Two Technologies

Long-term Tagging Technology

Events Detection and Condition Monitoring Technology

MSU PFG Technology

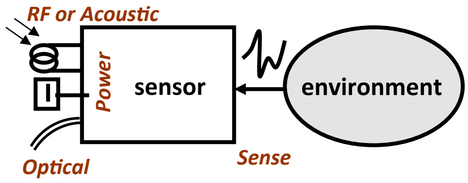
- **Sensors embedded inside "smart structures" that can self-prognosticate damage and mechanical failure.**
- **Zero Maintenance Sensors:** Operational life of sensors comparable to the useful life of the structure – Powering is one of the key challenges.



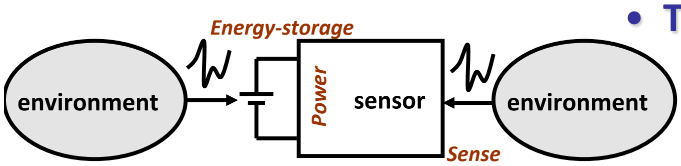
Sensor Size and Powering

Self-powered Sensors

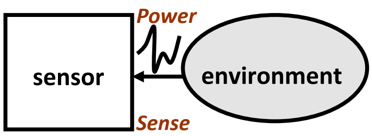
- Sensors that operate by scavenging energy from the ambient environment.



- **Passive Sensors**
  - Sensor is active only when the interrogation signal present – radio-frequency, optical or acoustic sensing. **(NOT Zero-downtime – cannot sense rare events)**



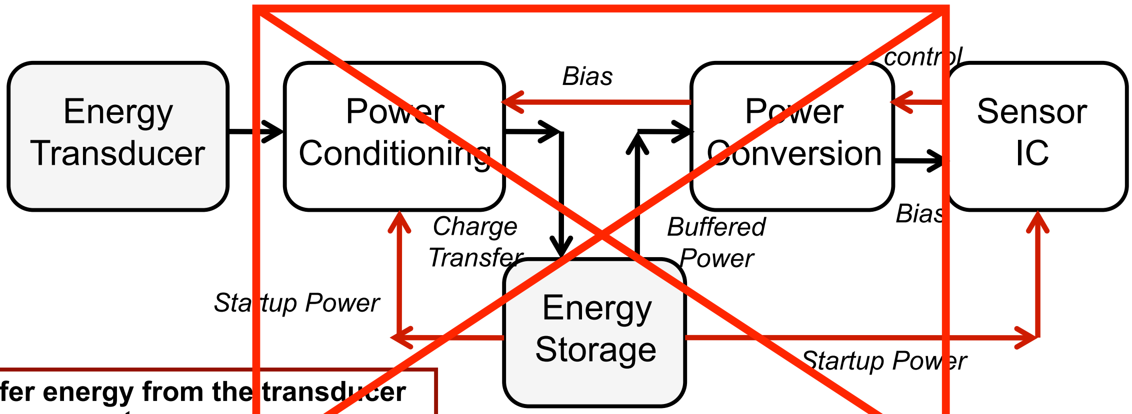
- **Trickle-charge Sensors**
  - Energy stored by trickle-charging and active only when powering conditions met. **(NOT Zero-downtime – cannot sense rare events)**



- **Direct-powered Sensors**
  - Harvest energy for operation from the signal being sensed – e.g. piezoelectric signal used for powering and sensing mechanical strain.

Can we use existing commercial solutions ?

- **Harvestable power too little to be mapped onto existing solutions.**



Transfer energy from the transducer to the energy storage

1. Power Efficiency (Output Power/ Input Power)
2. Leakage (important in sleep mode)
3. Source Impedance Matching (maximum power transfer)
4. Start up power

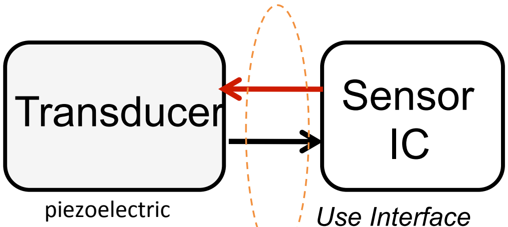
Convert buffered energy into regulated power required for multi-voltage, multi-function biasing

1. Conversion Efficiency
2. Dynamic Range
3. Start up power

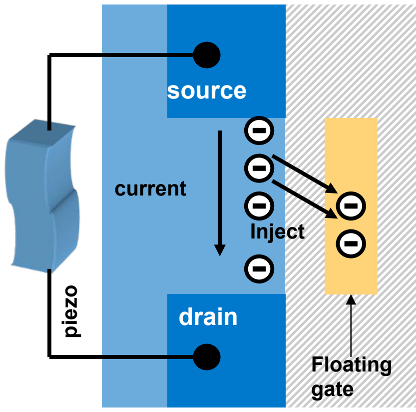
Piezo-floating-gate technology

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

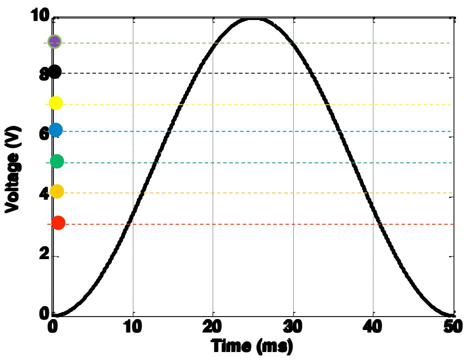
Eliminate power regulators, energy storage, data converters, RAMs and digital signal processors. Use the physics of the device and the structure to perform computation and storage (Use analog computation instead of digital).



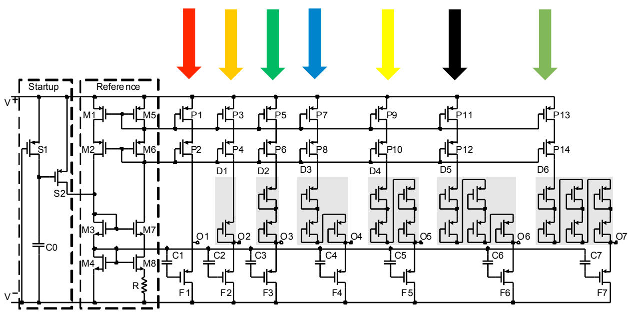
Use Interface physics for sensing computation and storage

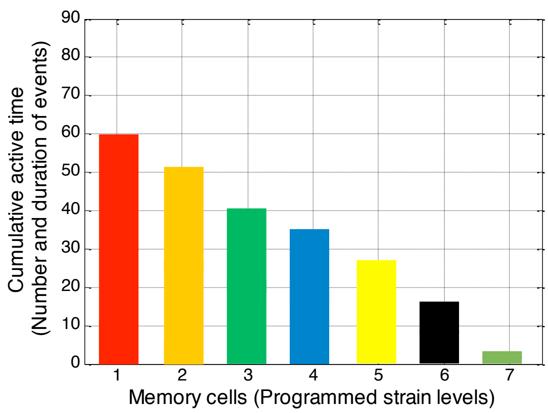


- **Piezoelectric ceramics and polymers can generate high-voltages for low strain-levels but at ultra-low-driving currents.**

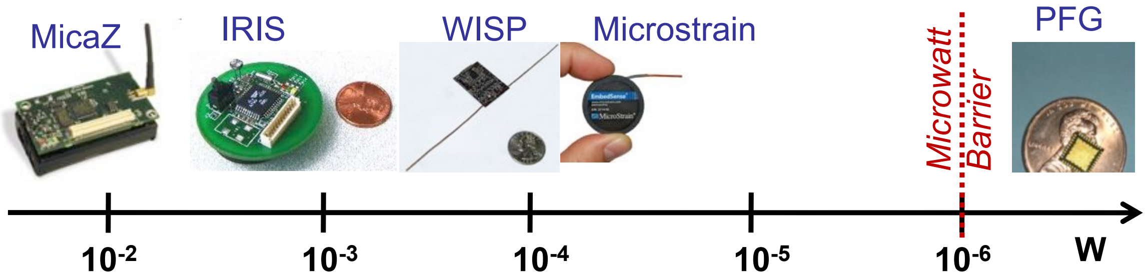


Recorded data on the sensor





Comparison with other technologies

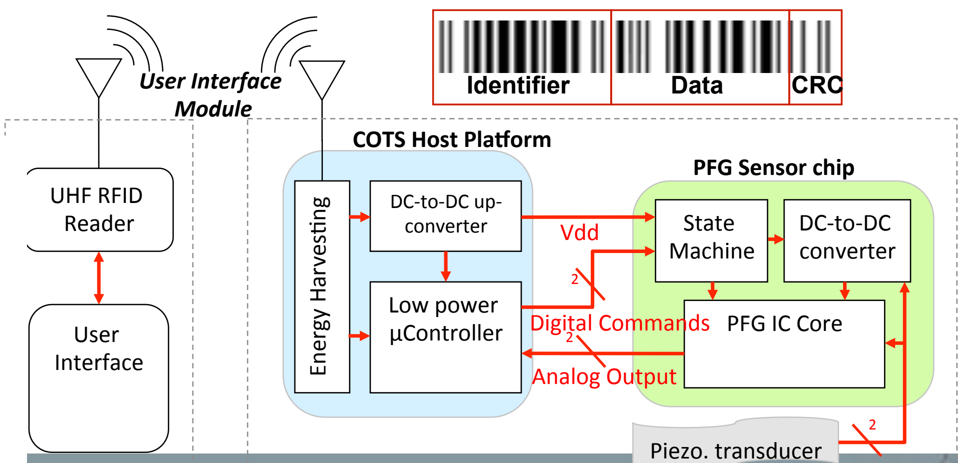


Process	0.5-μm standard CMOS
Size	1900μm x 1500μm
Maximum Current consumption	110nA (7-channel level crossing monitoring)
	90nA (3-channel impact monitoring)

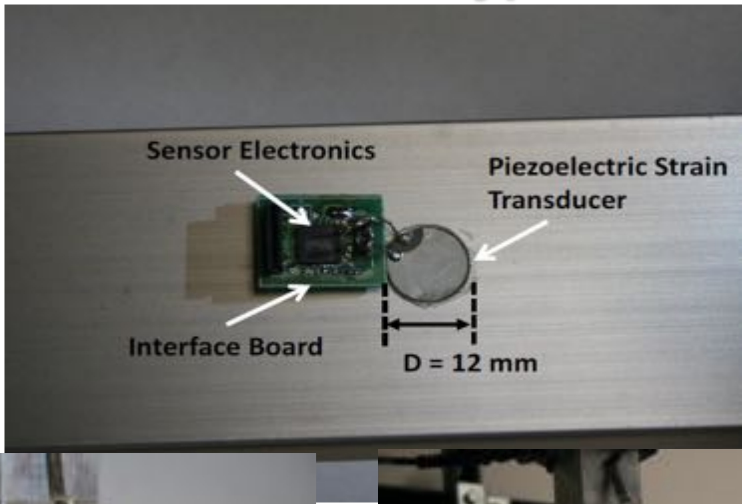
Interfacing PFG with Gen-2 RFID

Commercial Readers

- Mechanical usage data in the EPC is continuously updated on the non-volatile memory and is powered by strain-variations.
- COTS platform (MSP430 based) to implement the Gen-2 protocol stack (derived from WISP).

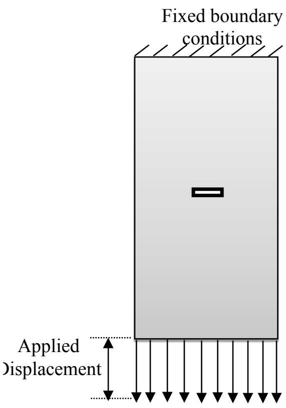


Tested Prototypes

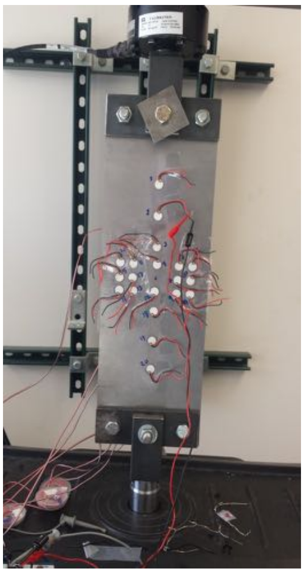


Damage was introduced by making a notch at the middle of the steel plate. The damage states were defined by increasing the notch size (2a) as follows:

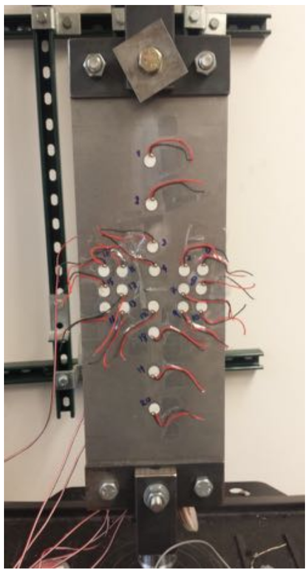
Intact: 2a= 0 mm (Intact plate)
D10: 2a = 10 mm
D20: 2a = 20 mm
D30: 2a = 30 mm
D40: 2a = 40 mm



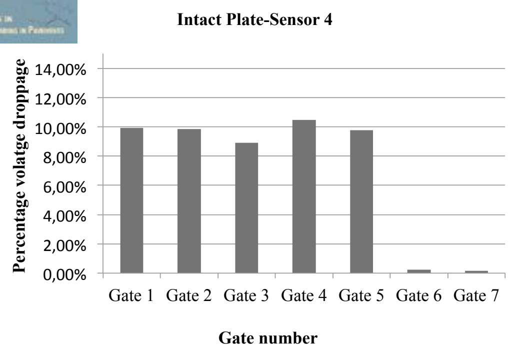
Strain gages

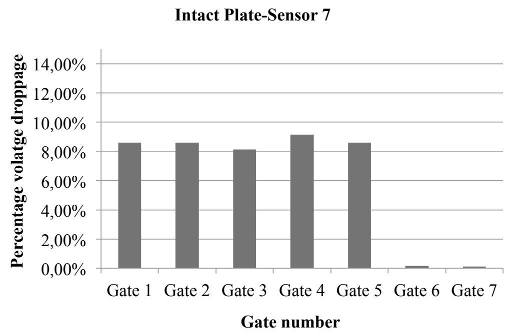


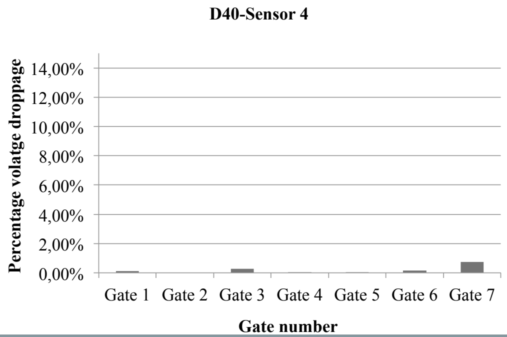
Intact plate

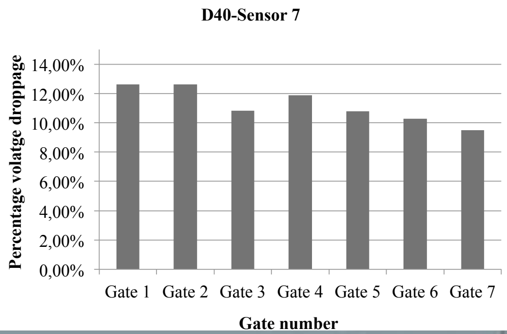


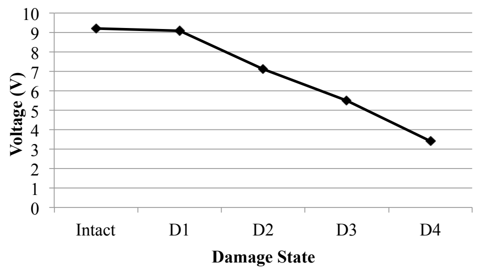
Notched plate

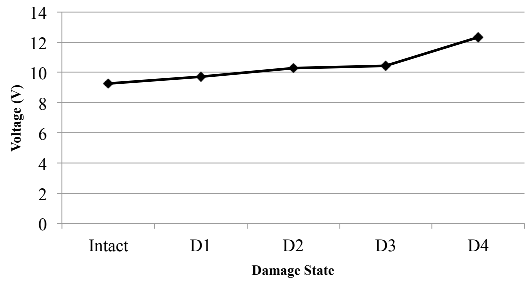


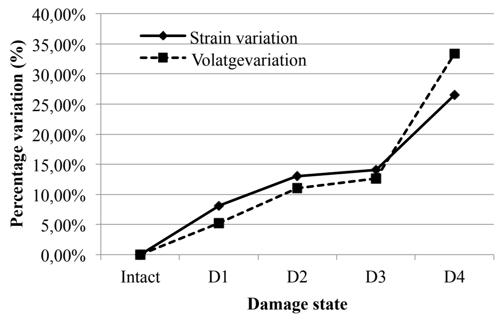




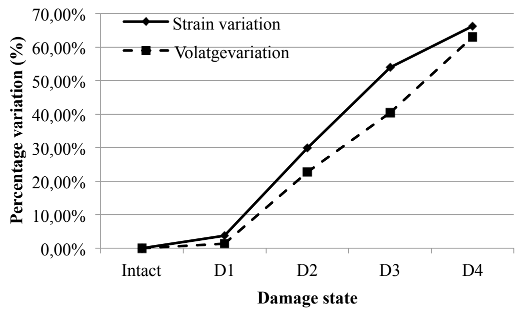








Sensor 4



Sensor 7

Looking into the Future

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