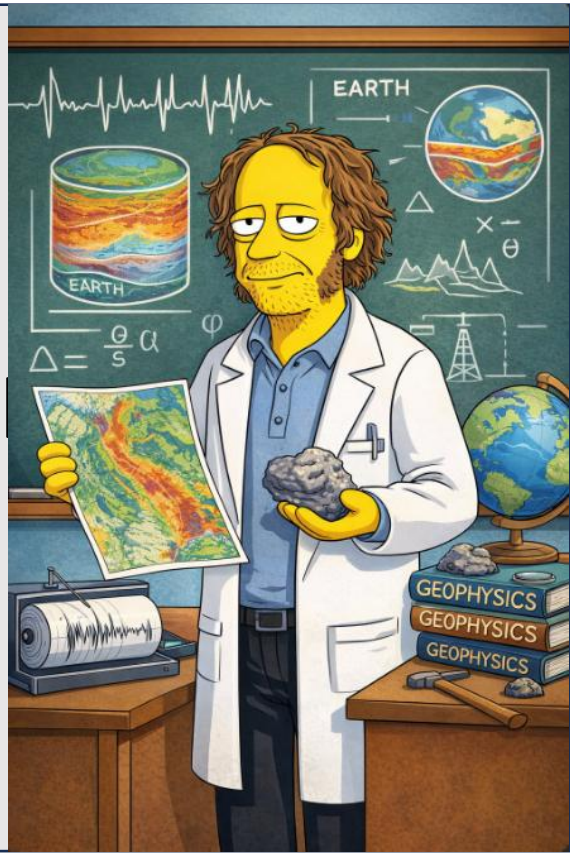
UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING

COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY



Research Area	Focus
Imaging Geophysics	Advanced subsurface imaging using reflection, vertical seismic profiling, and cross well tomography, and DAS geophysical methods
Microseismic Methods	Advanced analysis of subsurface systems using microseismic data utilizing b-value and moment magnitude-based calculations
Well Log Analysis and Interpretation	Advanced petrophysical analysis using geophysical wireline well logs and advanced workflows.
Electromagnetic Geophysics	Use multifrequency airborne and helicopter borne electromagnetic geophysics to determine subsurface water quality and topology of water systems.
Magnetics	Use magnetic potential field for determination of well and borehole related features.
Cement Stability and Tectonics	Model petrophysical properties of cement and foam cement relative to formation containment and well bore stability. Use 3D stress models to determine induced seismicity potential and fluid flow potential through fracture of fault systems.

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City Infrastructure Monitoring using Dark Fiber Networks

Khurram Naeem, Paul R. Ohodnicki, and William Harbert

University of Pittsburgh

June 3, 2026

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Dark Fiber DAS for Urban Infrastructure Monitoring: From Stanford Pilot to Pittsburgh Deployment

Pengdi Zhang [3], Prince Panta [2], Khurram Naeem [2], Haipeng Li [4], Tieyuan Zhu [5], Paul R. Ohodnicki [2], Mohamed Hamdallah [1], William Harbert
[1] Geology & Environmental Science [2] Mechanical Engineering & Materials Science · University of Pittsburgh · [3] National Energy Technology Laboratory · [4] Department of Geophysics, Stanford University · [5] Department of Geophysics, Pennsylvania State University

Background & Motivation

- **Aging urban infrastructure**
  - Bridges, pipelines, roads, light rail, water mains all rest on shallow subsurface materials
  - Foundation stiffness changes drive infrastructure-failure risk
- **Dark fiber as a city-wide sensor**
  - DAS converts a single fiber into thousands of virtual seismic sensors
  - ϕ-OTDR: 5–10 m spatial resolution, up to 40 km range, 1 Hz – 10 kHz
  - Already buried beneath every major city — no new trenching
- **Urban "noise" as a seismic source**
  - Traffic, rail, construction generate continuous broadband energy
  - Enables Passive MASW where geophones are impractical

GOAL: *Convert existing Pittsburgh dark fiber into a high-density subsurface observatory for infrastructure resilience.*

Pittsburgh Deployment Plan

- **Target corridor: 1–10 km dark-fiber loop**
  - Oakland-to-Downtown service area
  - DAS interrogator available at Energy Innovation Center
  - Access negotiated with City of Pittsburgh & INSITES partners
- **Three ground-truth sites**
  - Bridge deck, high-traffic intersection, quiet residential zone
  - 3-axis accelerometers + GPS clocks calibrate fiber strain
  - Edge-compute nodes log labels for ML event classification
- **Three-phase implementation (9–12 months)**
  - Phase 1: secure fiber, tap-test fiber-to-GPS mapping
  - Phase 2: intensive acquisition + ground-truth deployment
  - Phase 3: labeled "Steel City" dataset — routine noise vs. labeled anomalies and uncertainty.

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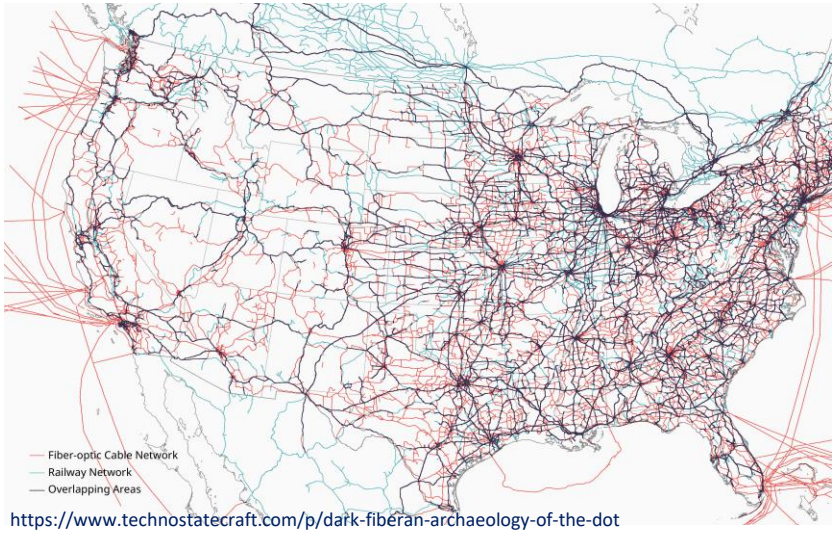
City Infrastructure Sensing using Dark Fiber Networks

❑ **Dark Fiber network in the U.S.**

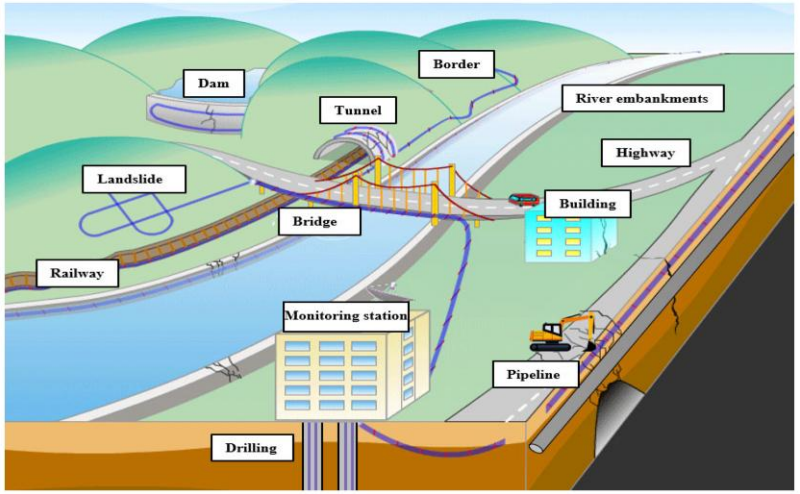


https://www.technostatecraft.com/p/dark-fiberan-archaeology-of-the-dot

Dark fibers – unused optical fibers in existing telecom cables or spare strands in new deployments

- Already installed → **zero civil cost**
- Long, continuous routes → **ideal for real-time distributed sensing**
- Often located near **critical infrastructure assets** (bridges, roads, utilities)

❑ **City Infrastructure Monitoring**



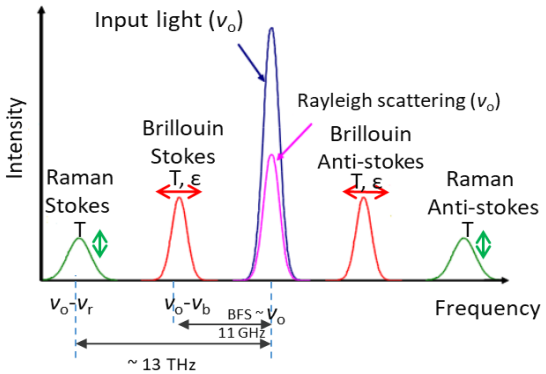
Real-time distributed sensing:

- Seismic & vibration monitoring
- Pipeline / tunnel / bridge health monitoring
- Railway & subway surveillance
- Urban security monitoring

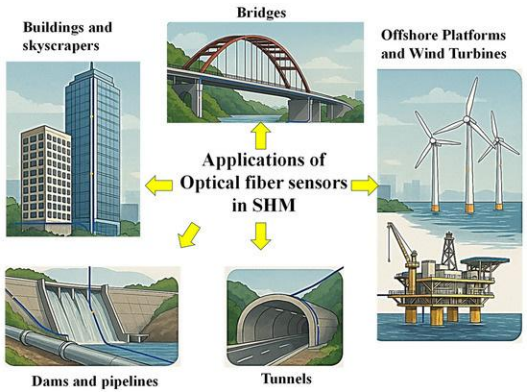
City Infrastructure Sensing using Dark Fiber networks

❑ Distributed Fiber Optics Sensing (DFOS)

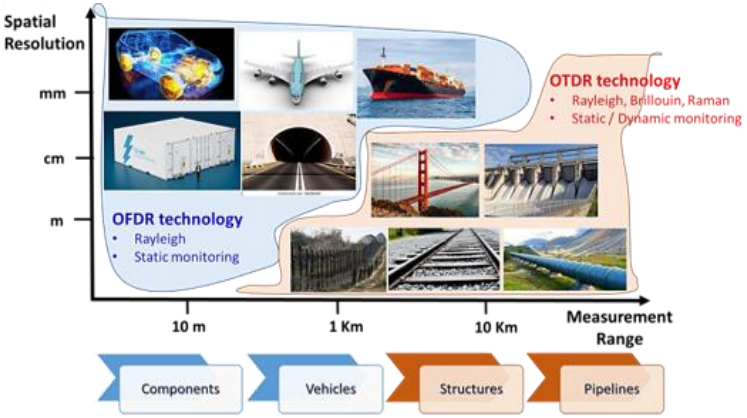
Scattered light spectrum of optical fiber

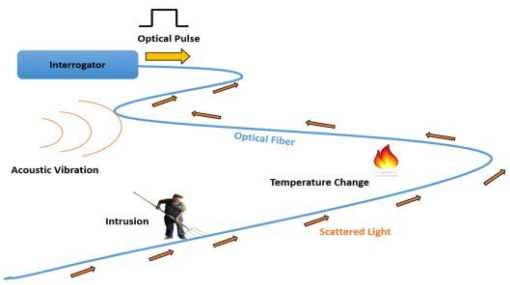


Applications



Types of DFOS





- **Fiber optic cable act as a Transducer and Dataline**
- **Real-time Monitoring of diverse parameters**
- **Long measurement range upto 100 Km**
- **Ability to simultaneously monitor:**
  - **Acoustic, Vibration, Temperature and Strain**

Distributed Sensing Over Different Length Scales

Overview of Fiber Optics Sensors R&D

University of Pittsburgh

- Intelligent Infrastructure monitoring applications for Long-range
- Novel Fiber sensors technologies: instrumentation and prototyping
- Integration of ML/AI data analytics
- Static and Dynamic monitoring of:
  - Strain
  - Temperature
  - Vibration / Acoustics
  - Biochemical / Gas /VOCs

Natural Gas, Oil, & H_2 Transport, Storage & Plants

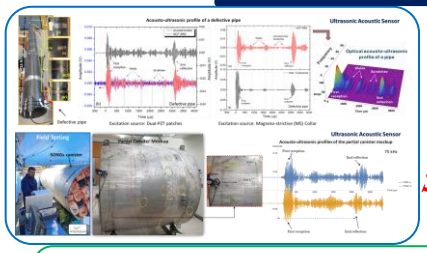
Civil (Road, Bridges, Water)

Electricity Grid Transport & Transformer

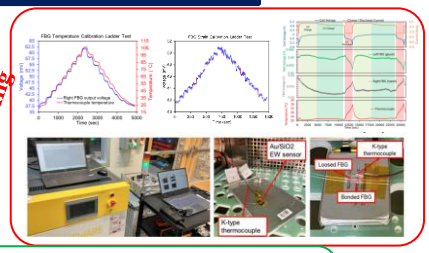
Conventional & Renewable Generation

Sensing applications and Field Demos.

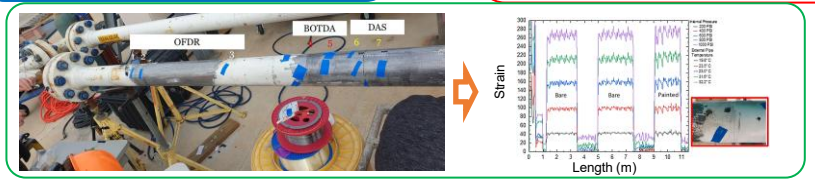
Ultrasonic Acoustic NDE



Li-Ion Battery monitoring

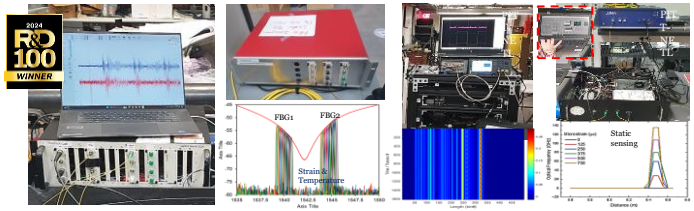


Energy Pipelines monitoring



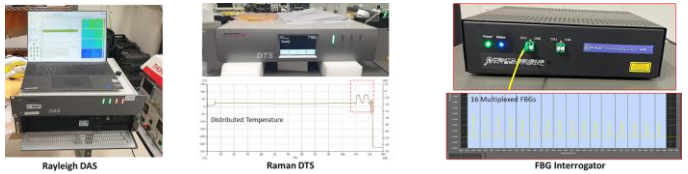
Optical Interrogation Systems Development

Custom developed



Ultrasonic Acoustic Interrogator | FBG interrogator | Rayleigh DAS | Rayleigh OFDR

Commercial Systems



Rayleigh DAS | Raman DTS | FBG Interrogator

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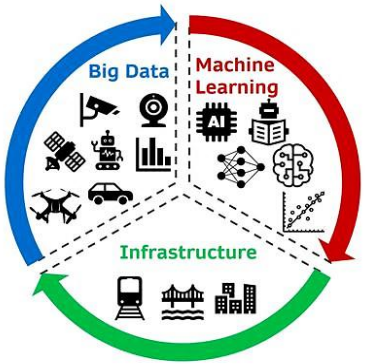
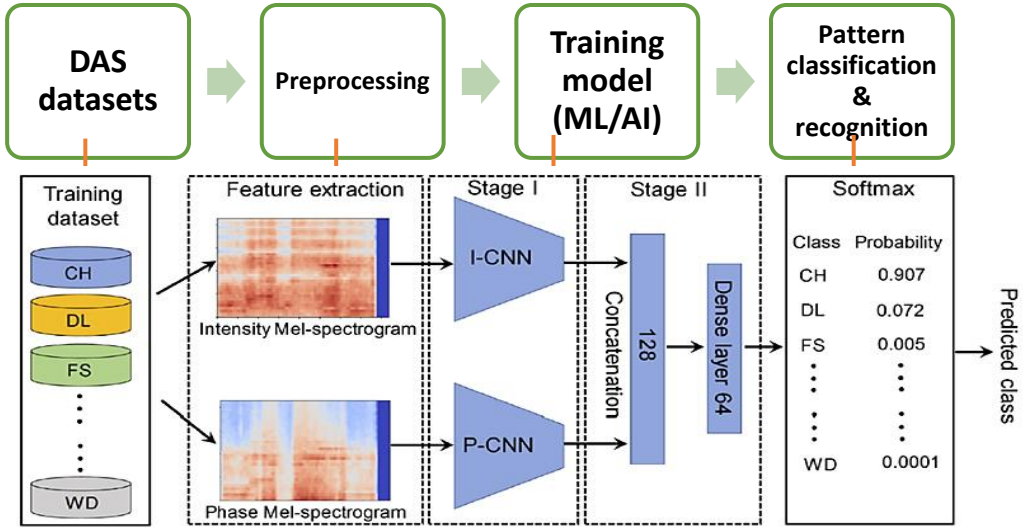
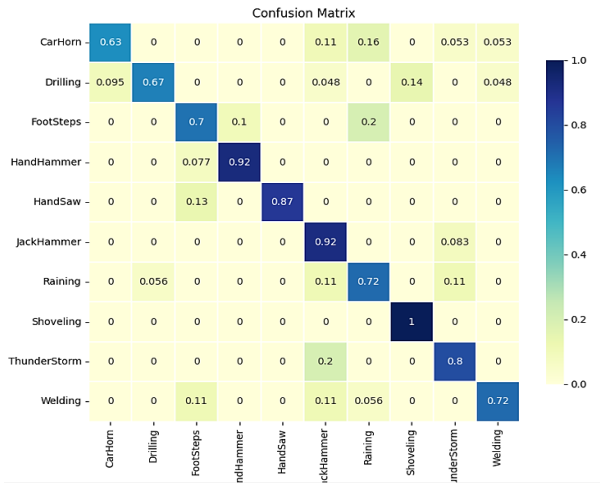
Intelligent Infrastructure Sensing using Dark Fiber networks

A Fusion of Sensory data & AI/ML

- **Development** of High-quality Datasets:
- **Data processing**: Pre-processing and AI/ML models
- **Development and Validation** of ML/AI models

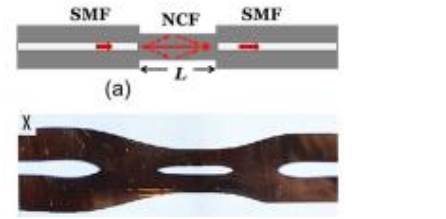


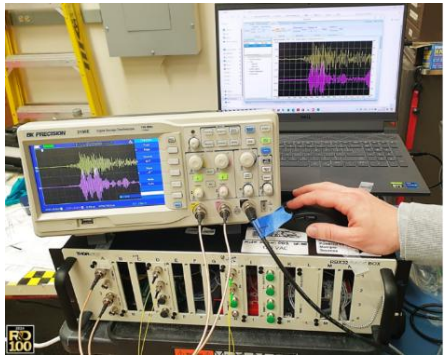




Fiber-optic sensors for Acoustic NDE

Pipeline condition monitoring





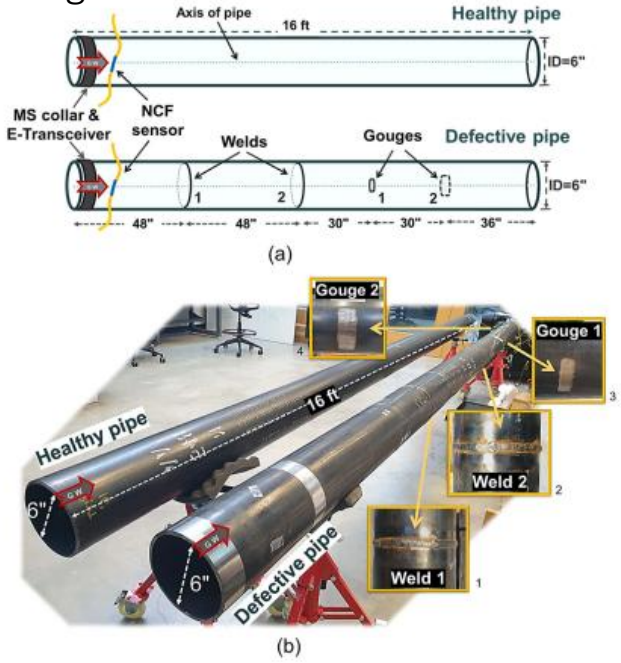
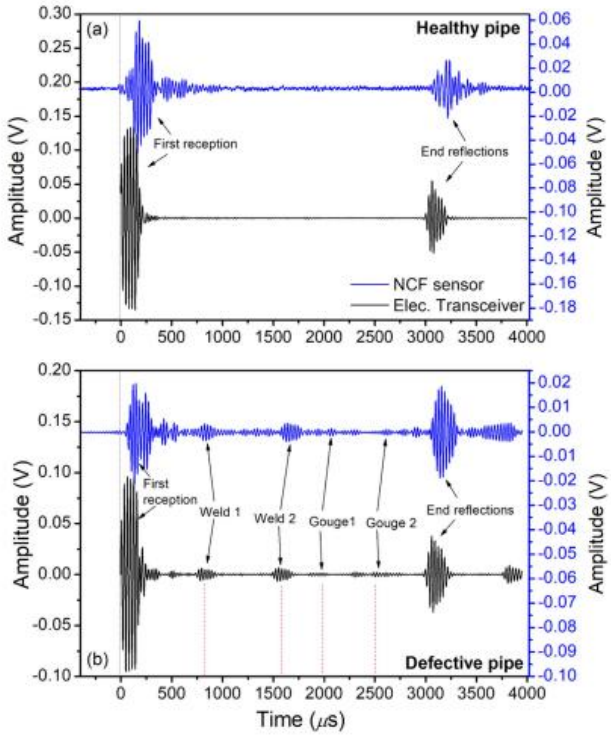


Fig. 13. (a) Schematics of healthy and defective carbon-steel pipelines (16 ft length, 6.625-inch OD, SCH 40). (b) Actual pipelines test setup in the laboratory.



K NAEEM et al.: NO-CORE FIBER BASED MULTIPOINT ULTRASONIC ACOUSTIC SENSORS

- **Near real time processing of DAS networks for**
  - Anomaly detection
  - Structural imaging
  - Infrastructure health monitoring, including electrical systems
  - Surface wave inversion for 2d material property profiles
  - Pipeline monitoring
  - Geohazard mitigation

- **Scientific deliverables**
  - DAS based anomaly detection and identification workflows
  - Pittsburgh-specific dv/v + Vs sections beneath critical infrastructure
  - Jupyter dashboards & GUIs for monitoring, event detection, labelling, uncertainty analysis
  - Reusable workflows for any urban dark-fiber deployment

- **Broader impacts**
  - Regional shallow-subsurface stiffness maps from existing infrastructure
  - Cross-disciplinary proof-of-concept for smart-city resilience
  - Foundation for NSF / DOT proposal at the geophysics ↔ engineering interface

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Acknowledgements

- William Harbert visited the Geophysics Department at Stanford University and worked with Dr. Biondo Biondi, Dr. Robert Clapp and an advanced Ph.D. graduate student Mr. Haipeng Li.

- Software for processing DAS datasets was generously shared by *Mr. Haipeng Li* at Stanford University, along with some DAS datasets and then these were shared with University of Pittsburgh Engineering graduate students, and a recent Ph.D. graduate (Pengdi Zhang PhD, ORISE NETL).
- A visit to GoogleX by William Harbert, and an excellent remote presentation from the Energy Center by Pengdi Zhang to the GoogleX team were positively received, with suggestions of future collaboration during the meeting.
- We are processing 10 Tb of previously recorded DAS data generously provided by our collaborator *Dr. Tieyuan Zhu* from his NSF funded Pittsburgh array. Acquire

References Cited:

- Liu, J., H. Li, S. Yuan,H. Y. Noh, and B. Biondi (2025a).Characterizing Vehicle-Induced Distributed Acoustic Sensing Signals for Accurate Urban Near-Surface Imaging, Seismol. Res. Lett. 96, 2867–2880, doi: 10.1785/0220240344.
- Liu, J., Li, H., Noh, H.Y. *et al.* Urban sensing using existing fiber-optic networks. *Nat Commun* **16**, 3091 (2025b). https://doi.org/10.1038/s41467-025-57997-y
- Penn State / CMU Metro21 FORESEE-GeoHazards project page: https://sites.psu.edu/pittsburghhazards/

Additional resources.

- Advanced seismic interpretation and well log analysis capabilities acquired from Schlumberger with advanced industry capabilities (Petrel, ECLIPSE, and TechLog); total donation value in USD, $77,819,394.34 (three-year agreement).

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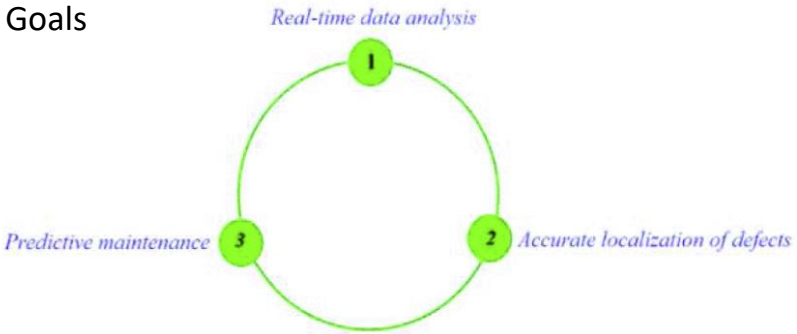
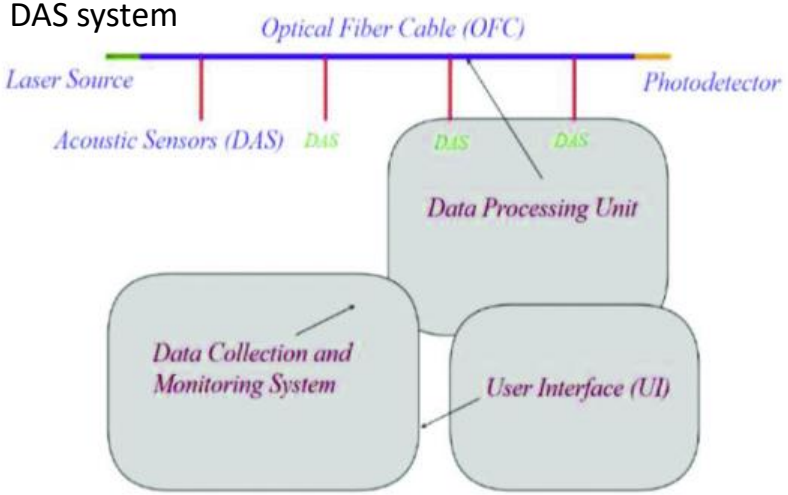
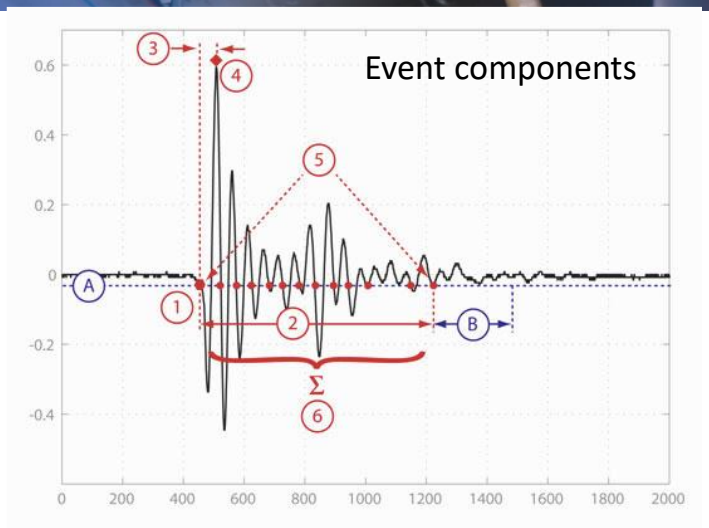
Goals

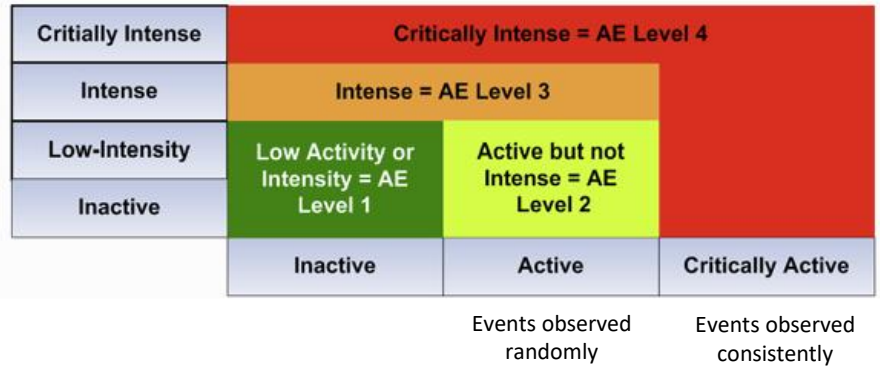


DAS system



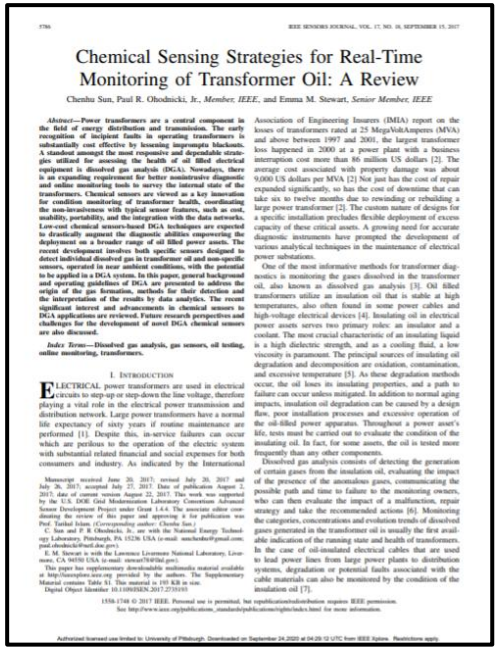
From: A. Kuttybayeva, A. Abdykadyrov, G. Tolen, A. Burdin, V. Malyugin and D. Kiesewetter, "Application of Distributed Acoustic Sensors Based on Optical Fiber Technologies for Infrastructure Monitoring," 2024 International Conference on Electrical Engineering and Photonics (EExPolytech), Saint Petersburg, Russian Federation, 2024, pp. 23-26, doi: 10.1109/EExPolytech62224.2024.10755937.





Self-sustaining Wireless Acoustic Emission Sensor System for Bridge Monitoring, 2011
Ákos Lédeczi, Péter Völgyesi, Eric Barth, András Nádas, Alexander Pedchenko, Thomas Hay, and Subash Jayaraman, in S.C. Mukhopadhyay (Ed.): New Developments in Sensing Technology for SHM,

Review Articles Relevant to Fiber Optic and Infrastructure Sensing

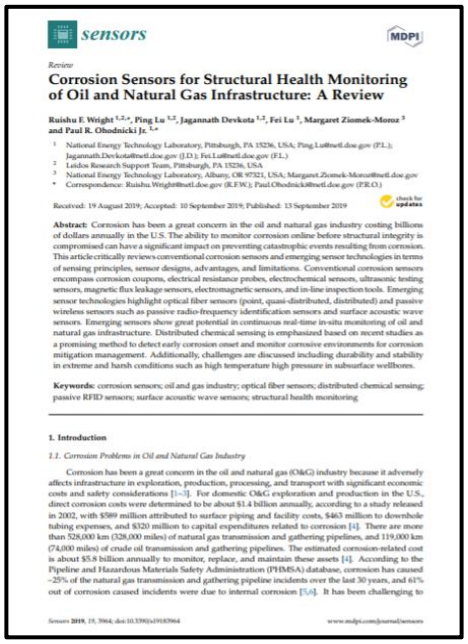


Chemical Sensing Strategies for Real-Time Monitoring of Transformer Oil: A Review

Chenhu Sun, Paul R. Ohodnicki, Jr., *Member, IEEE*, and Emma M. Stewart, *Senior Member, IEEE*

IEEE Sensors Journal, vol. 17, no. 18, pp. 5786-5806, 15 Sept.15, 2017

Applied Physics Reviews **5**, 011102 (2018)



Sensors 19(18), 3964 (2019)

Examples of Recent Review Articles that May Be of Interest for Further Review