RIIS
RESILIENT, INTELLIGENT INFRASTRUCTURE SYSTEMS

Australian Government
Australian Research Council

RIIS Project Presentations
Thursday 14th March 2024

RESILIENT AND INTELLIGENT INFRASTRUCTURE SYSTEMS

in urban resources and energy sectors.

Presentation Chair

Professor Sisi Zlatanova

CHAIR

Acknowledgment of Country

We acknowledge Aboriginal nations as first people of Australia, we thank them for their custodianship of the land and pay respects to Elders past and present

UNSW SYDNEY

RIIS

RIIS Director

Scientia Professor Nasser Khalili

ARC Industry Transformation Research Hub

Nasser Khalili
Hub Director
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WESTERN SYDNEY UNIVERSITY
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INDUSTRY PARTNERS

GeoAI

Azure Mining Technology

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Asset Institute®
OPTIMISE SUSTAIN TRANSFORM

IPWEA
INSTITUTE OF PUBLIC WORKS ENGINEERING AUSTRALASIA

MINCKA

WOOLPERT

Geoscape

FRONTIER SI

South East Water

Spatial Vision

EMERSON

Ports Australia

ROOBUCK

HAWK

Lindenbaum

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RESEARCH THEMES

Research and Innovation Themes

The RIIS has the potential to transform advanced manufacturing, service and infrastructure engineering in Australia focusing on five main themes:

THEME 1 Sensing, intelligent and adaptive systems

- Robust, low energy sensors and actuators
- Ubiquitous positioning, sensing & communications
- Internet of Things (IoT) & sensing platforms
- Signal processing, network and sensing optimization

THEME 2 Data collection, security and integration

- Robotics, satellite, UAV, autonomous systems
- Big data management storage & transmission
- Data security, robustness and reliability

THEME 3 Modelling, simulations and prognostics

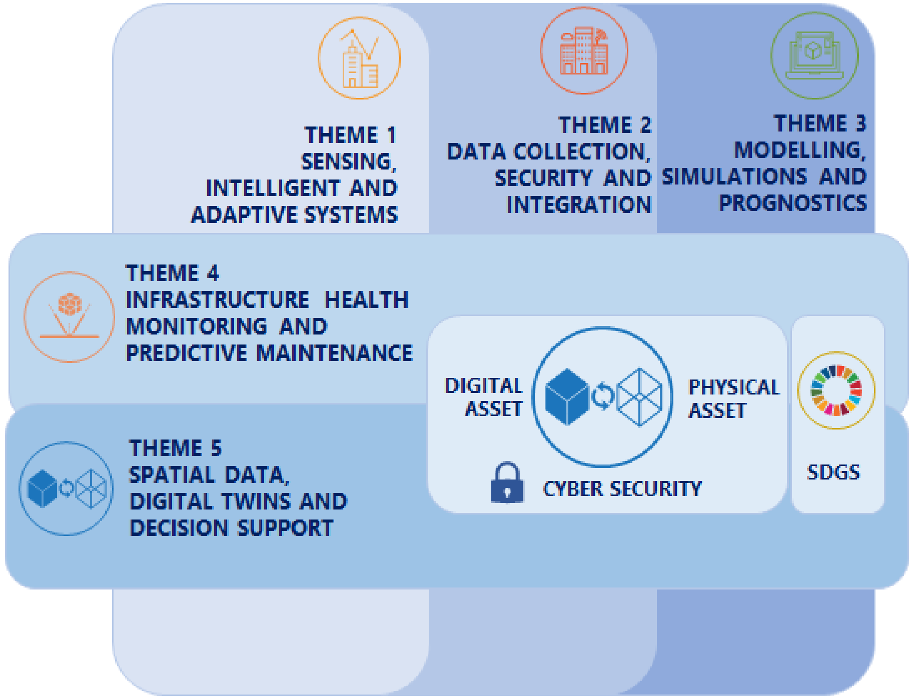
- Predictive modelling simulation & performance assessment
- Physics-informed artificial intelligence machine learning
- Real-time analytics – adaptive decisions

THEME 4 Infrastructure monitoring and predictive maintenance

- Degradation quantification & failure prediction Risk & safety
- Service life assessment
- Remedial & renewal technologies

THEME 5 Spatial data, Digital Twins and decision support

- Integration & structuring of data & prognosis
- Digital twins & decision support
- Visualisation, virtual reality & interactive guidance systems
- Adaptive, intelligent & resilient design



THEME 1 LEAD

THEME 1

Ubiquitous sensing, intelligent and adaptive systems

Theme 1 Lead

Professor Ismet Canbulat

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THEME 3 PROJECT

Dr Babak Shahbodagh

A Computational Framework for Structural Health Monitoring of Geo-Infrastructures

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“TOWARDS PRODUCTIVE, CONNECTED, SUSTAINABLE AND SMART INFRASTRUCTURE”

Project Title: A Computational Framework for Structural Health Monitoring of Geo-Infrastructures

Involved:

UNSW CIs: Prof Nasser Khalili, Dr Babak Shahbodagh, Dr Mohammad Vahab

Collaborator: Dr Ehsan Haghighat (Massachusetts Institute of Technology - MIT)

PhD Students: Sana Shahoveisi, Sina Akhyani

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Introduction

Geo-structures - Dams, Roads, Rails, Levees, Embankments, Foundations, Tunnels, Slopes, etc.

- Significant Consequence of Failure

Failure of Yallourn East Field Mine, VIC 2007.

Failure of 50 levee banks along the River Murray, SA 2022.

Jamberoo Mountain Road Failure, NSW 2020.

Aim

Develop a Computational Framework for

Structural Health Monitoring of Geo-Infrastructures

Failure of Yallourn East Field Mine, VIC 2007.

Failure of 50 levee banks along the River Murray, SA 2022.

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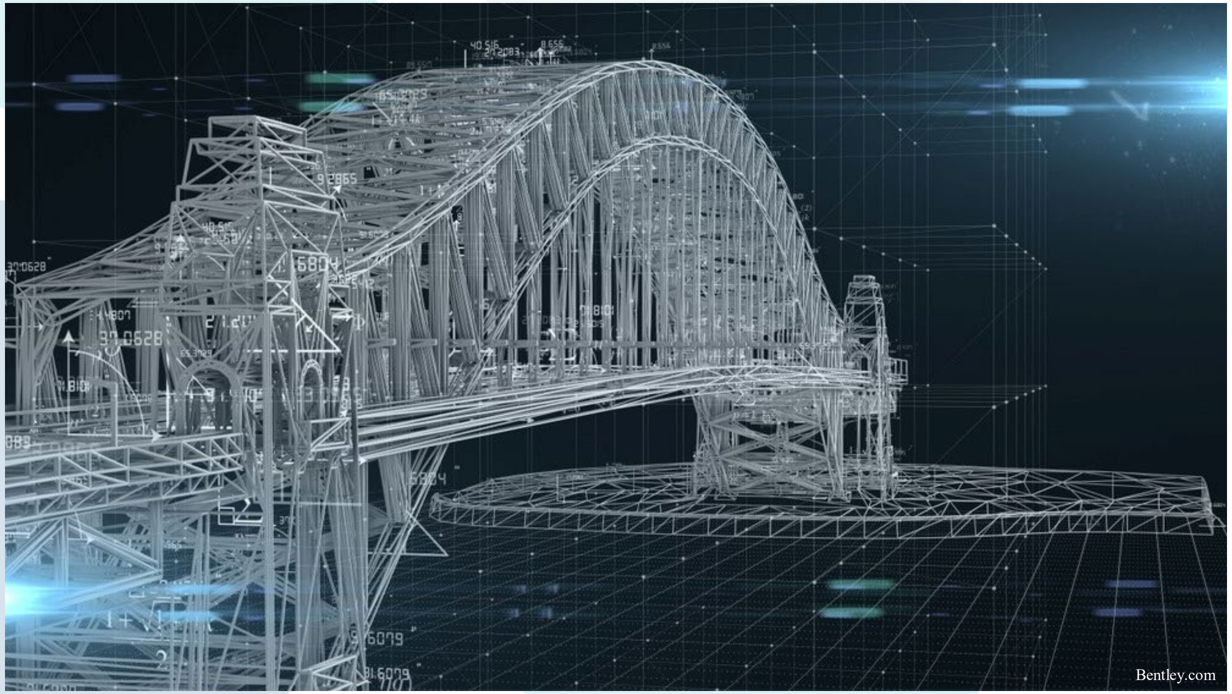
Aim

Develop a Computational Framework for

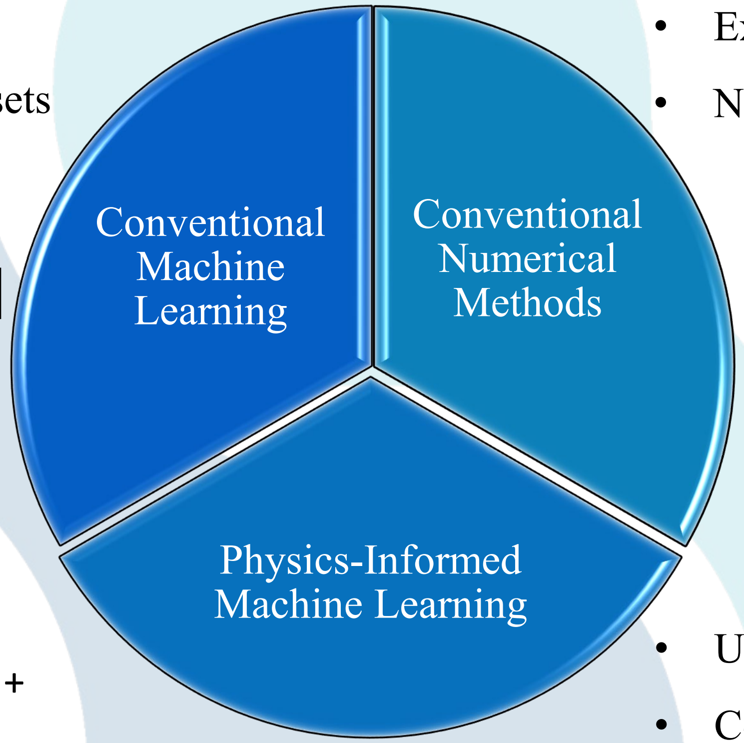
Structural Health Monitoring of Geo-Infrastructures



Physics-Informed AI Framework

- Black box AI models
- Requires extensive datasets
- Failure in extrapolation

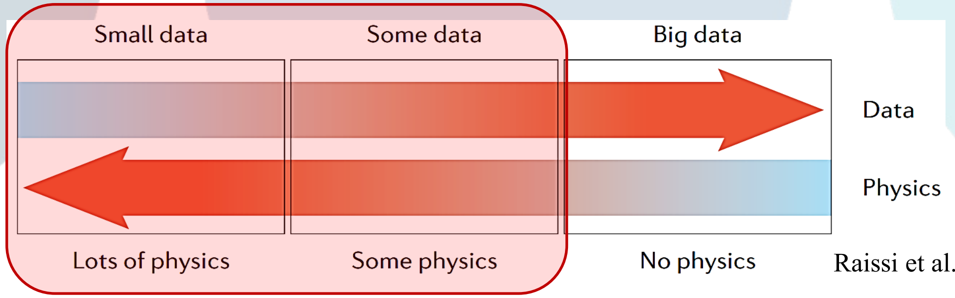
$$\arg\min L(\mathbf{x}^*) \coloneqq \|f^* - \hat{f}(\mathbf{x}^*)\|$$



- Extensive computational cost
- Not suitable for inverse analysis

$$\arg\min L(\mathbf{x}^*) \coloneqq \|f^* - \hat{f}(\mathbf{x}^*)\| + \|\mathcal{P}\mathbf{x} - 0\|_{\Omega} + \|\mathcal{C}\mathbf{x} - g\|_{\partial\Omega} + \ldots$$

- Use of physics & field data
- Computationally efficient
- Excellent performance in inversion



Raissi et al. (2019); Karniadakis et al. (2021)

Physics-Informed AI Framework

Pile-Soil Interaction Problem

Governing Equations:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\sigma^{\alpha}_{rr}) + \frac{1}{r}\frac{\partial\sigma^{\alpha}_{r\theta}}{\partial\theta} + \frac{\partial\sigma^{\alpha}_{rz}}{\partial z} - \frac{\sigma^{\alpha}_{\theta\theta}}{r} + f^{\alpha}_{r} = 0\ ,$$

$$\frac{1}{r}\frac{\partial}{\partial r}(r\sigma^{\alpha}_{r\theta}) + \frac{1}{r}\frac{\partial\sigma^{\alpha}_{\theta\theta}}{\partial\theta} + \frac{\partial\sigma^{\alpha}_{\theta z}}{\partial z} + \frac{\sigma^{\alpha}_{r\theta}}{r} + f^{\alpha}_{\theta} = 0\ , \qquad \text{on } \Omega_{\alpha}\ (\alpha = P,\ S_k)$$

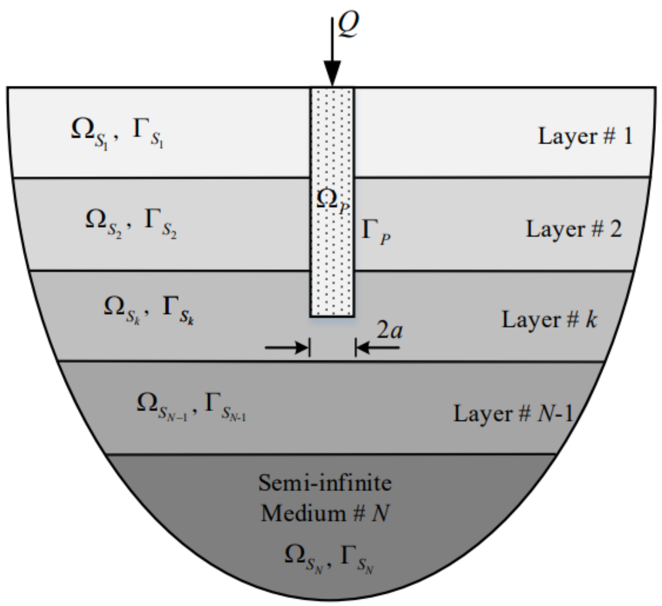
$$\frac{1}{r}\frac{\partial}{\partial r}(r\sigma^{\alpha}_{rz}) + \frac{1}{r}\frac{\partial\sigma^{\alpha}_{\theta z}}{\partial\theta} + \frac{\partial\sigma^{\alpha}_{zz}}{\partial z} + f^{\alpha}_{z} = 0\ ,$$

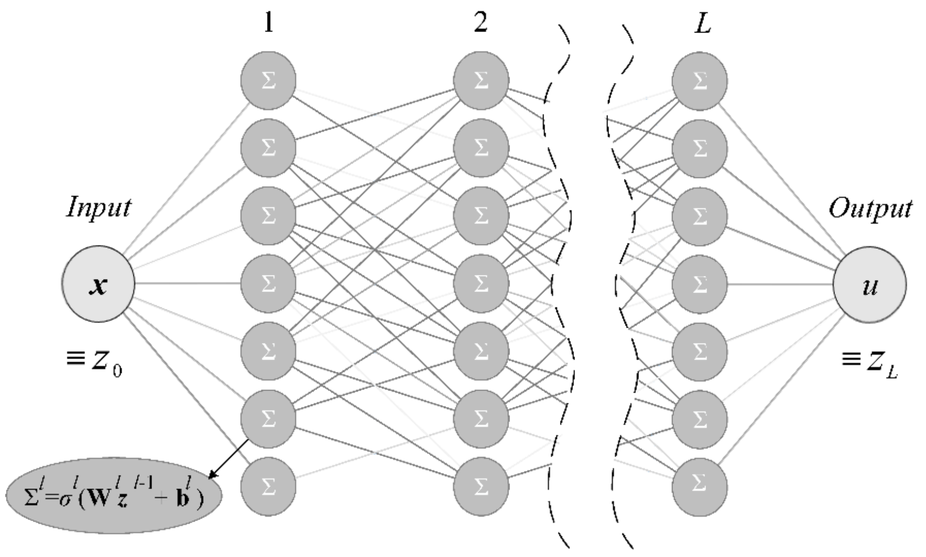
$$\varepsilon^{\alpha}_{ij} = \frac{1}{2}\left(u^{\alpha}_{i,j} + u^{\alpha}_{j,i}\right)$$

Pile-Soil Interface:

$$\left(\sigma^{\alpha}_{ji}(\boldsymbol{x}) - \sigma^{\beta}_{ji}(\boldsymbol{x})\right) n^{\alpha}_{j} = 0\ , \qquad \forall \boldsymbol{x} \in (\Gamma_{\alpha} \cap \Gamma_{\beta}),\ \text{where}\ \ \alpha \neq \beta$$

$$u^{\alpha}_{i}(\boldsymbol{x}) - u^{\beta}_{i}(\boldsymbol{x}) = 0\ ,$$





PROJECT UPDATE – BABAK SHAHBODAGH

Physics-Informed AI Framework (PINN)

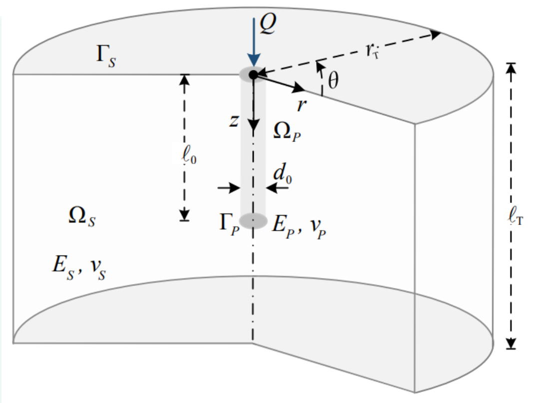
Pile-Soil Interaction Problem

$$\mathcal{L}_T = \mathcal{L}_\Omega + \mathcal{L}_{\Gamma_{\text{B.C.}}} + \mathcal{L}_{\Gamma_{\text{Cont}}} \quad ,$$

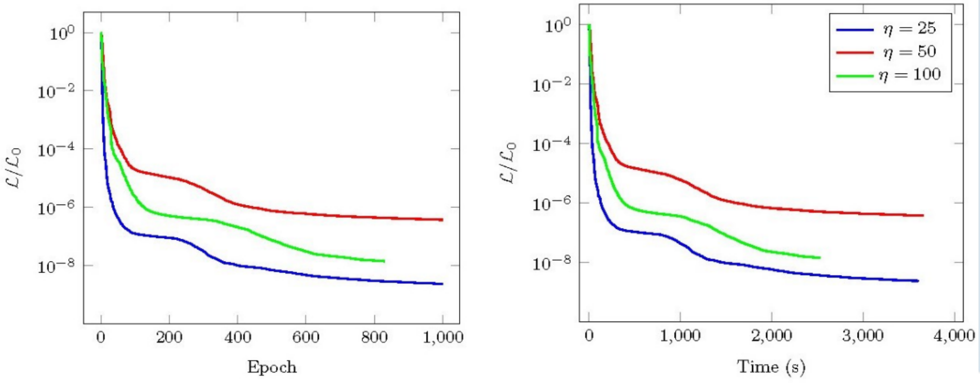
$$\mathcal{L}_\Omega = \lambda_1 \left\|\mathcal{P}^P_{rr}\mathbf{u}^P\right\|_{\text{on } \Omega_P} + \lambda_2 \left\|\mathcal{P}^S_{rr}\mathbf{u}^S\right\|_{\text{on } \Omega_S} + \lambda_3 \left\|\mathcal{P}^P_{zz}\mathbf{u}^P\right\|_{\text{on } \Omega_P} + \lambda_4 \left\|\mathcal{P}^S_{zz}\mathbf{u}^S\right\|_{\text{on } \Omega_S} \quad ,$$

$$\mathcal{L}_{\Gamma_{\text{B.C.}}} = \lambda_5 \left\|\mathcal{B}^P_{rr}\mathbf{u}^P - g^P_{rr}\right\|_{\text{on } \Gamma_P \setminus \Gamma_S} + \lambda_6 \left\|\mathcal{B}^S_{rr}\mathbf{u}^S - g^S_{rr}\right\|_{\text{on } \Gamma_S \setminus \Gamma_P} + \lambda_7 \left\|\mathcal{B}^P_{zz}\mathbf{u}^P - g^P_{zz}\right\|_{\text{on } \Gamma_P \setminus \Gamma_S} + \lambda_8 \left\|\mathcal{B}^S_{zz}\mathbf{u}^S - g^S_{zz}\right\|_{\text{on } \Gamma_S \setminus \Gamma_P} \quad ,$$

$$\mathcal{L}_{\Gamma_{\text{Cont}}} = \lambda_9 \left\|\mathbf{u}^P - \mathbf{u}^S\right\|_{\text{on } \Gamma_P \cap \Gamma_S} + \lambda_{10} \left\|\mathbf{t}^P - \mathbf{t}^S\right\|_{\text{on } \Gamma_P \cap \Gamma_S} \quad ,$$

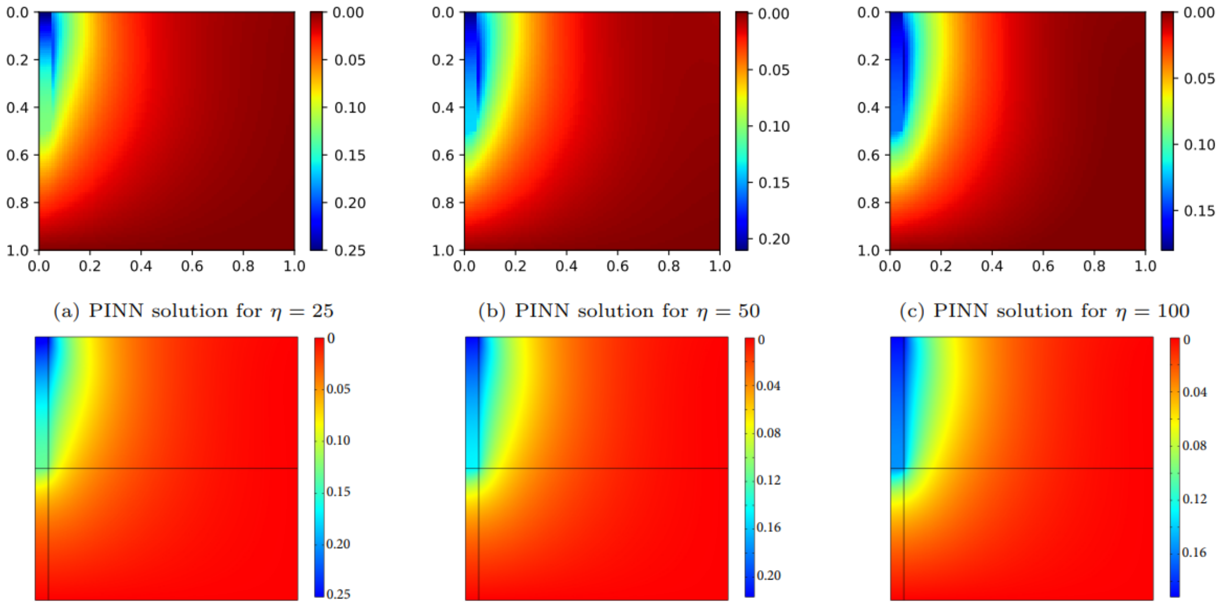


$$\eta = \frac{E_p}{E_s}$$



Networks training history

PINN



(a) PINN solution for $\eta = 25$

(b) PINN solution for $\eta = 50$

(c) PINN solution for $\eta = 100$

(d) Reference solution for $\eta = 25$

(e) Reference solution for $\eta = 50$

(f) Reference solution for $\eta = 100$

FEM

Normalised Vertical Displacement

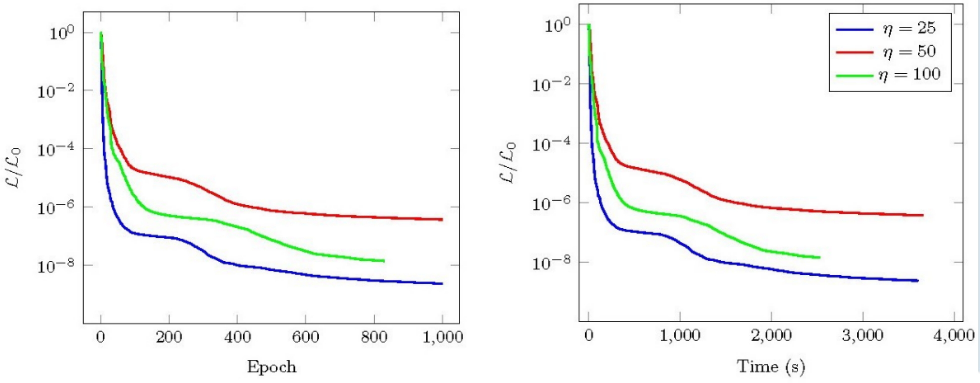
Physics-Informed AI Framework

Pile-Soil Interaction Problem

The computational complexity of the proposed PINNs solution vs the FEM analysis

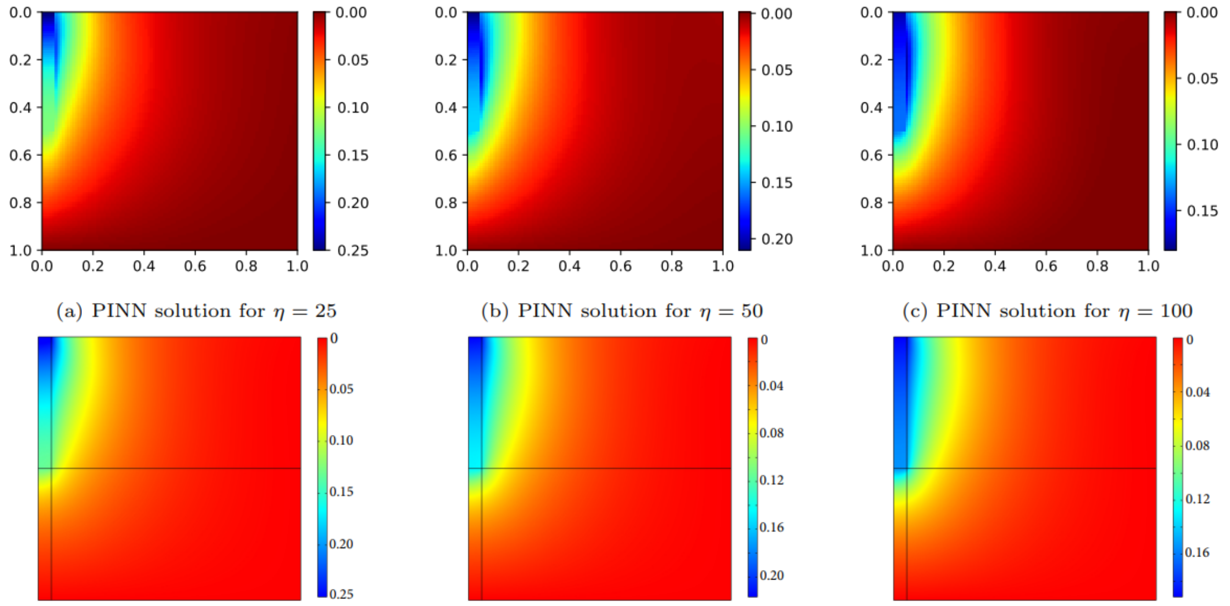
DOFs	PINNs (4 × 20)	Iterative solvers (IS)[a]	$\mathcal{O}_{IS}/\mathcal{O}_{PINN}$	Direct solvers (DS)[b]	$\mathcal{O}_{DS}/\mathcal{O}_{PINN}$
1000	3.2E+5	1.0E+7	31.2	5.0E+8	1562.5
6000	1.9E+6	3.6E+8	187.5	1.1E+11	56250
10,000	3.2E+6	1.0E+9	312.5	5.0E+11	156250

$$\eta = \frac{E_p}{E_s}$$



Networks training history

PINN



(a) PINN solution for $\eta = 25$ (b) PINN solution for $\eta = 50$ (c) PINN solution for $\eta = 100$

(d) Reference solution for $\eta = 25$ (e) Reference solution for $\eta = 50$ (f) Reference solution for $\eta = 100$

FEM

Normalised Vertical Displacement

Next Steps

Extension of the Physics-Informed Artificial Intelligence Framework for modelling

- **Coupled Hydro-Mechanical Problems**
- **Wave Propagation in Multiphase Porous Media**
- **Material Nonlinearity**
- **Initiation and Progression of Flaws in Multiphasic Materials**

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THEME 1 PROJECT

Dr Mahroo Bahador

Nanosensor Integration and Manufacturing Technology for Safe Mining

PROJECT UPDATE
GUANGZHAO MAO

CI – Professor Guangzhao Mao	Industry – Azure Mining Technology	UBIQUITOUS SENSING, INTELLIGENT AND ADAPTIVE SYSTEMS

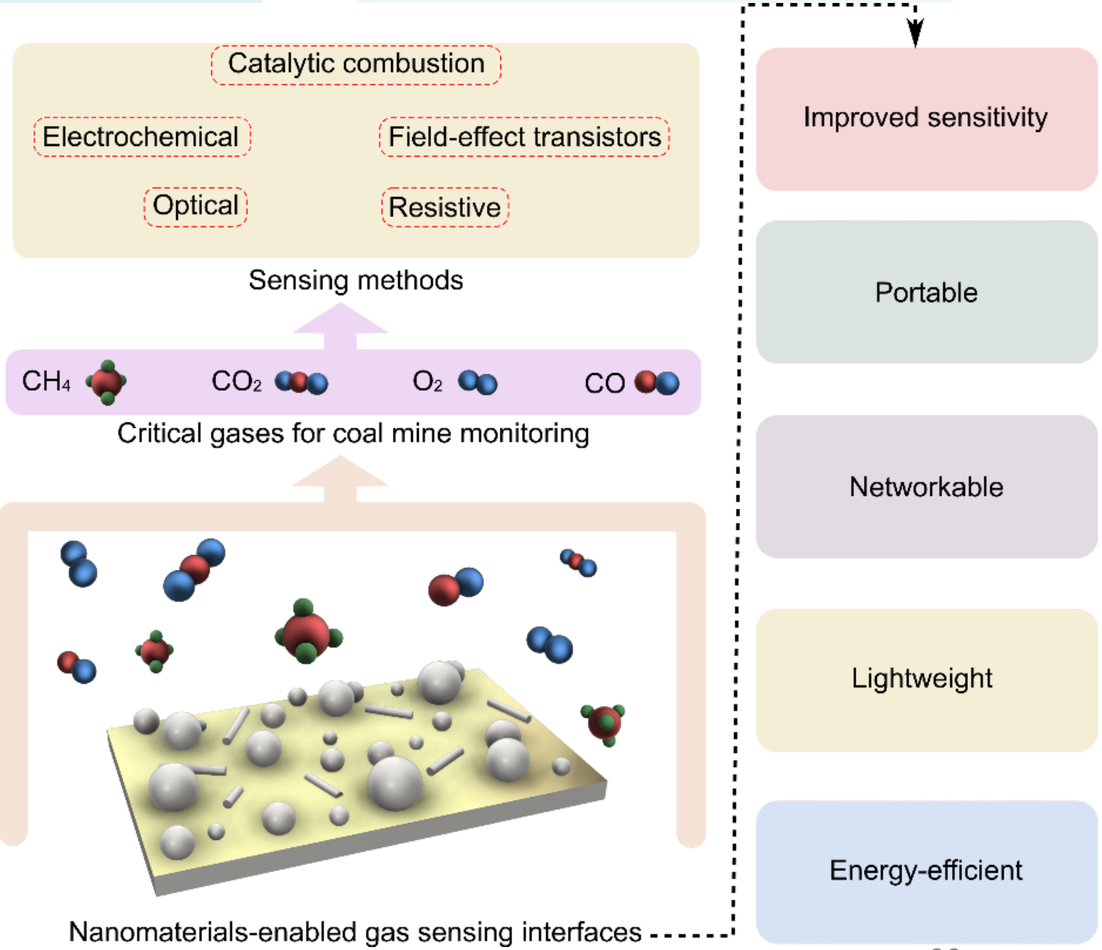
Project Title: Nanosensors Technology for Safe Mining

Motivation:

- ✓ Controlled crystallization of nanowires
- ✓ Enabling scalable manufacturing of miniaturized interconnected electronics suited for gas sensing.
- ✓ Addressing challenges of existing sensors such as limited sensitivity and low-selectivity.

Aims:

- ✓ Developing a scalable nanosensor manufacturing technique
- ✓ Tailoring selectivity by exploring different chemistries of NWs.
- ✓ Fabricating nanosensors with improved applicability and sensitivity.



M. Baharfar, J. Lin, et al., Nanoscale Advances, 2023, DOI: 10.1039/d3na00507k.

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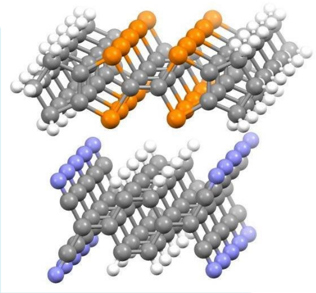
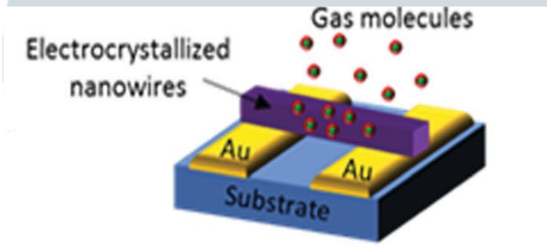
Gaps in knowledge:

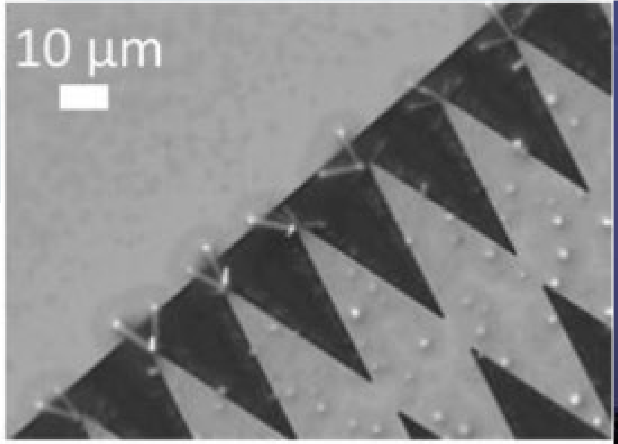
- lack of a reliable and scalable manufacturing technique for nanosensing interfaces.
- Performance of existing gas sensors in the market is yet to be improved.

Approach:

- Introducing controlled crystallization of nanowires on microelectrodes, as a reliable technology for scalable nanosensor manufacturing.
- Nanoscale gas sensing interfaces offer higher sensitivity, energy-efficiency, and potability.







L. Li, P. Jahanian and G. Mao, J. Phys. Chem. C, 2014, 118, 18771–18782.
Kilani M. *et al.*, Small Methods (2023).

PROJECT UPDATE
GUANGZHAO MAO

Milestone	Description	Progress
Phase 1		
1	Define technical parameters for nanosensor use for mining safety	Achieved
2	Demonstrate nanowire deposition reproducibility	Achieved
3	Demonstrate nanosensor performance for 4 hazardous scenarios in the mining field	Ongoing work
Phase 2		
4	One or more nanosensor prototypes completed on deployable platforms relevant to mining safety	Future work
5	Sensor device prototypes tested for reliability and stability in mining environments	Future work
6	Describe commercial production plan with our collaborators	Future work

Gas type	Standard No.	Detection range	Response time	Power consumption
Methane	AQ6203-2006	0-4%	<5s	2mW
Carbon monoxide	AQ6205-2006	0-1000ppm	<5s	2mW
Oxygen	MT981-2006	0-25%	<5s	2mW
Carbon dioxide	AQ1052-2008	0-5%	<5s	2mW

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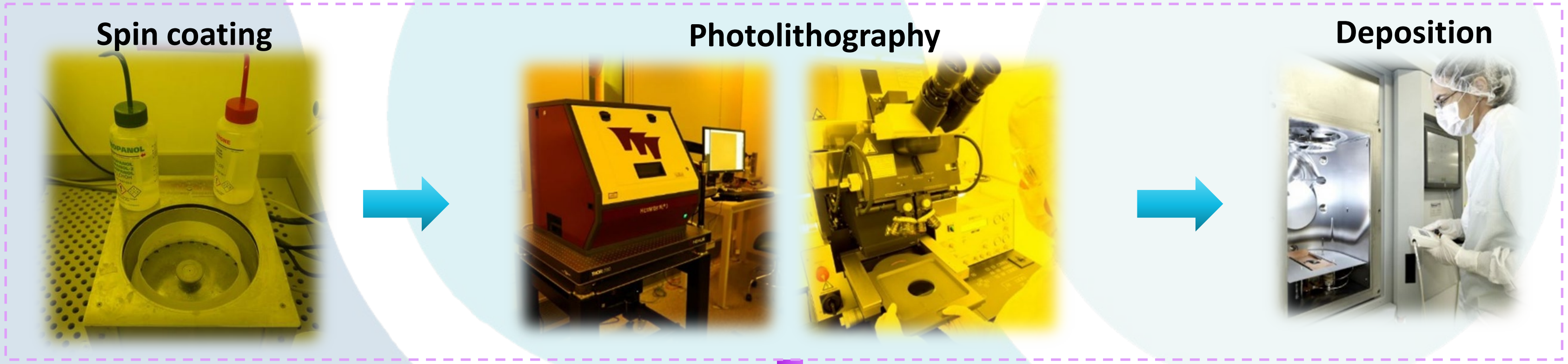
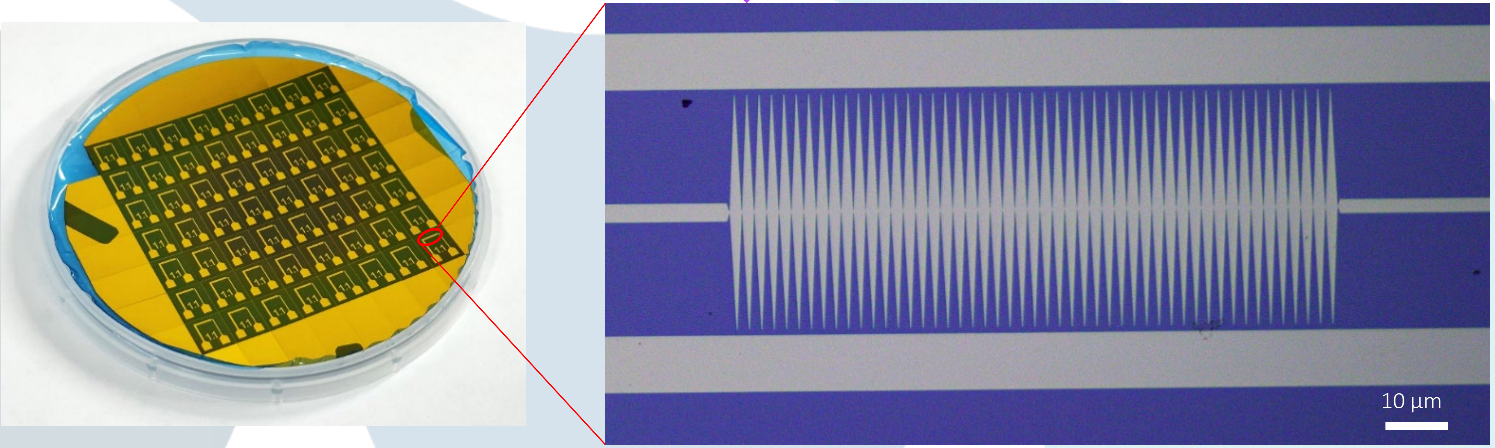
- **Fabrication of substrate prototypes**





PROJECT UPDATE
GUANGZHAO MAO

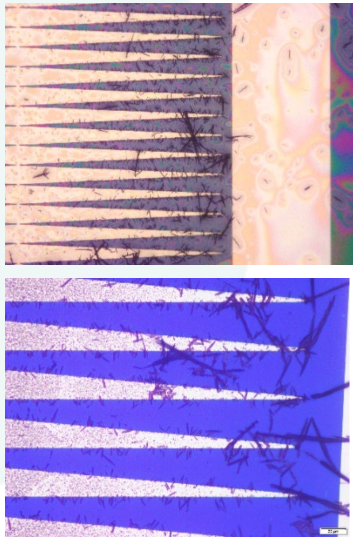
- **Developing gas sensing platforms**

Structures explored so far:

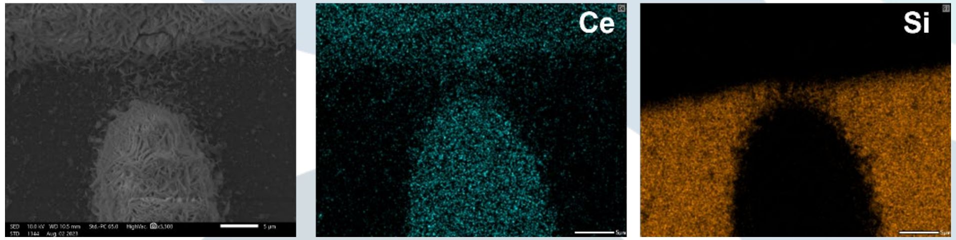
✓ Charge transfer complexes (TTFBr, TTFCl, TTFI, CuTCNQ, and TTF-TCNQ)

✓ Metal oxides (ZnO, CeO_2, and SnO_2)

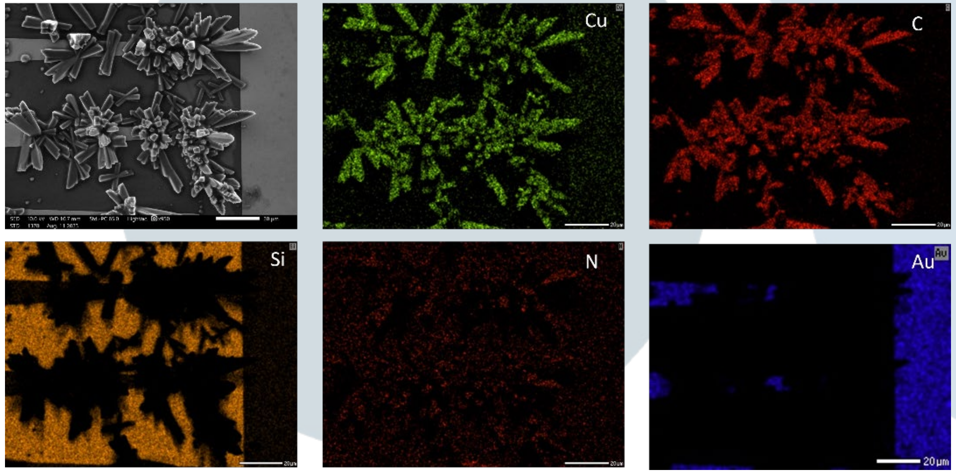
TTFBr



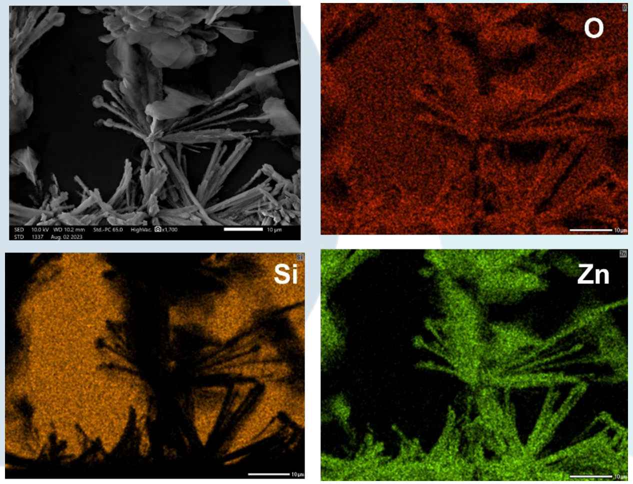
CeO_2

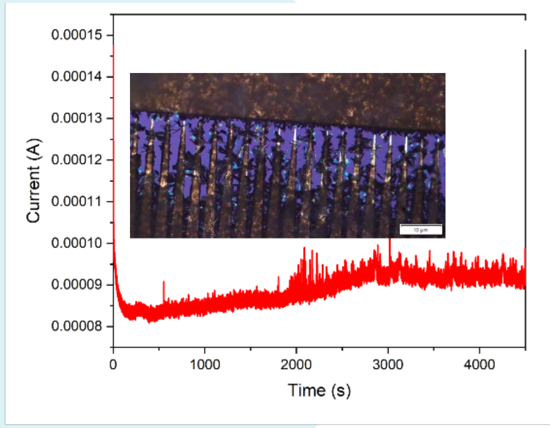


CuTCNQ



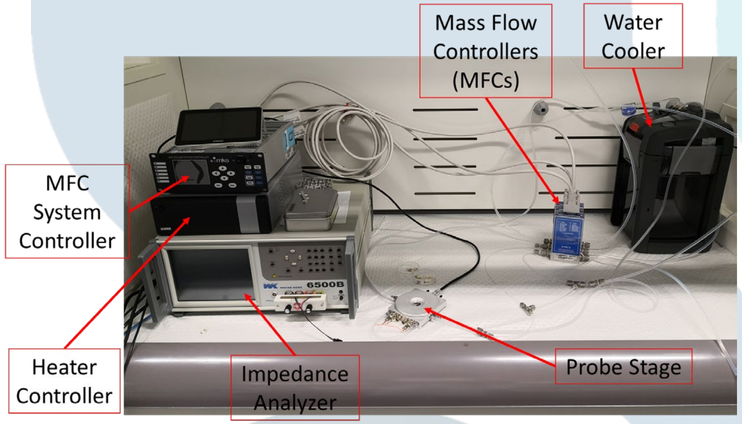
ZnO

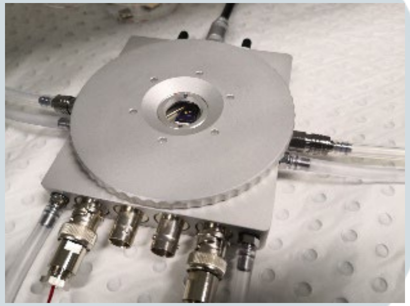


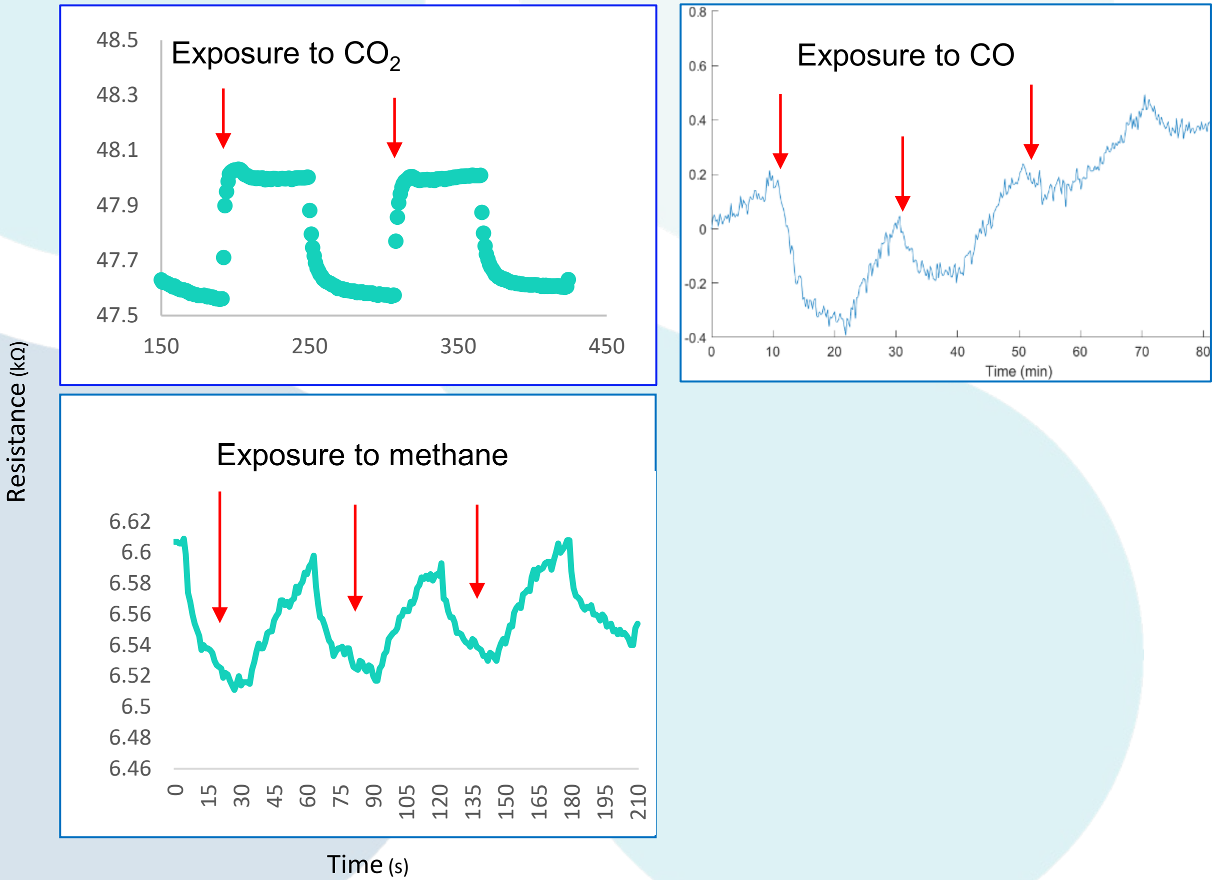


Ongoing Work

- **Demonstrate nanosensor performance for 4 hazardous scenarios in the mining field**







Summary and Future work

Progress:

- Defining technical parameters
- Fabricating substrate prototypes
- Exploring deposition of NWs

Ongoing work:

- Investigating the analytical figures for each gas

Future work:

- Nanosensor prototyping
- Reliability tests in mining fields

Dr Binghao Li & Dr Xu

Text message broadcasting system for underground mines and camera-based tracking & obstacle avoidance

PROJECT UPDATE
DR BINGHAO LI

CI – Binghao Li	Industry – Roobuck	Hub Theme 1,2,5

Project Title: Text message broadcasting system for underground mines and camera-based tracking

Background: In the challenging environments of underground mines, maintaining robust communication and ensuring the safety of personnel and equipment are paramount. This project leverages cutting-edge technologies to develop a solution that addresses these critical needs.

Objective: Develop a state-of-the-art text message broadcasting system coupled with a camera-based tracking and obstacle avoidance mechanism, designed specifically for the harsh conditions of underground mines. Fits seamlessly within the theme of resilient and intelligent infrastructure systems, focusing on improving the resilience of communication systems and the intelligence of safety mechanisms in extreme environments.

Technological Innovations:

- A broadcasting system designed for the extremely challenging underground environment.
- Deep learning-based low-light image enhancement technology and advanced object tracking solution.

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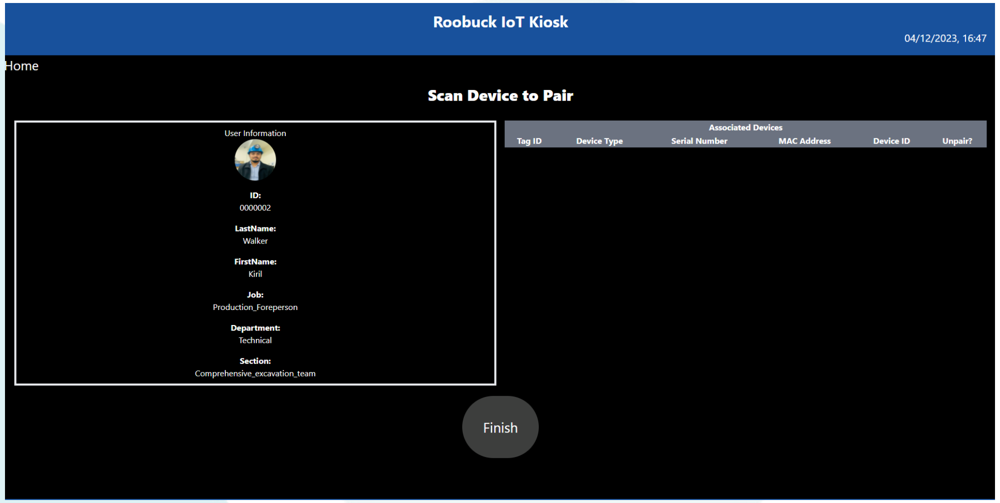
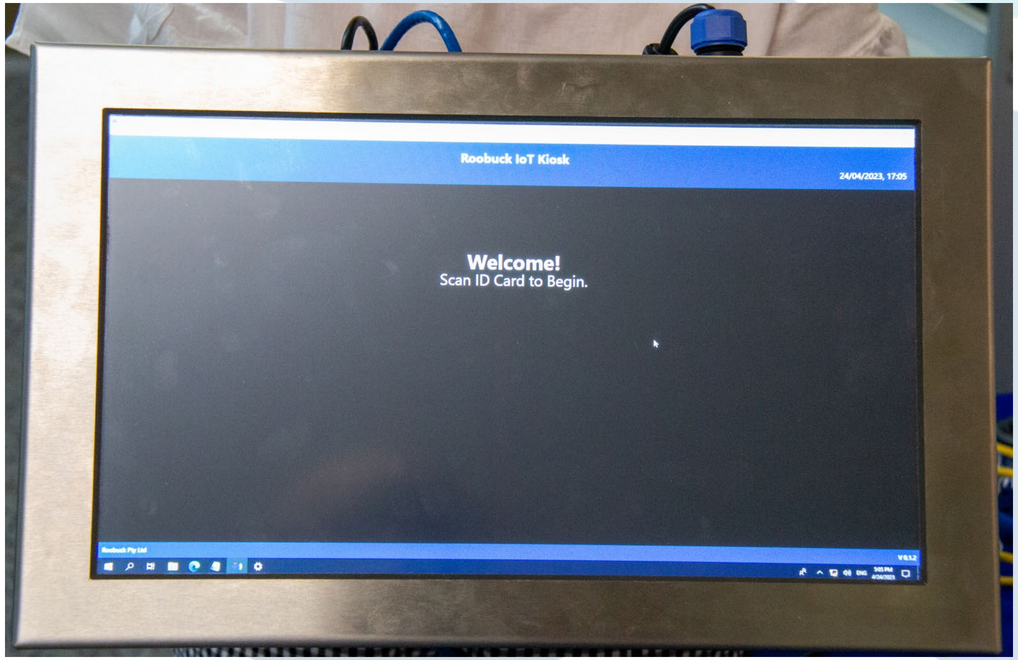
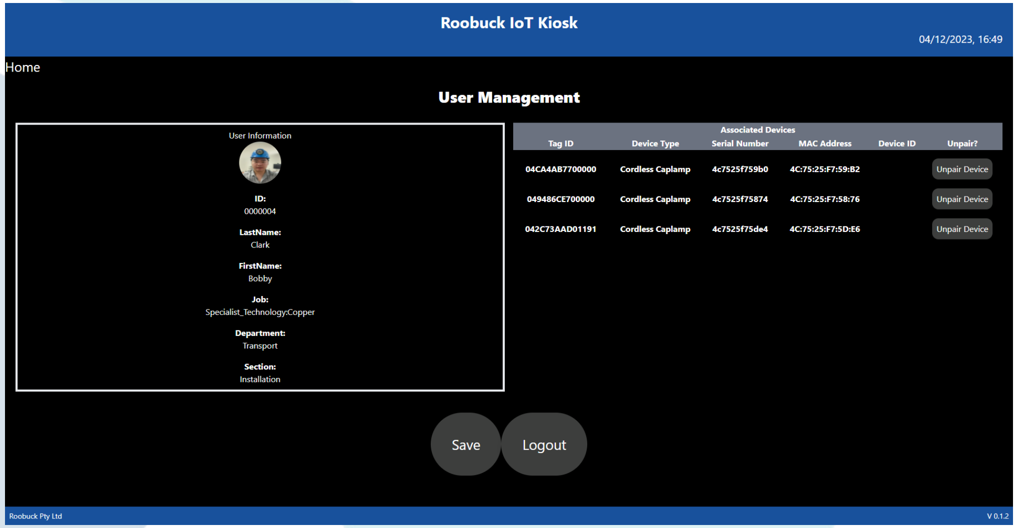
Kiosk System

This system can pair user information and devices







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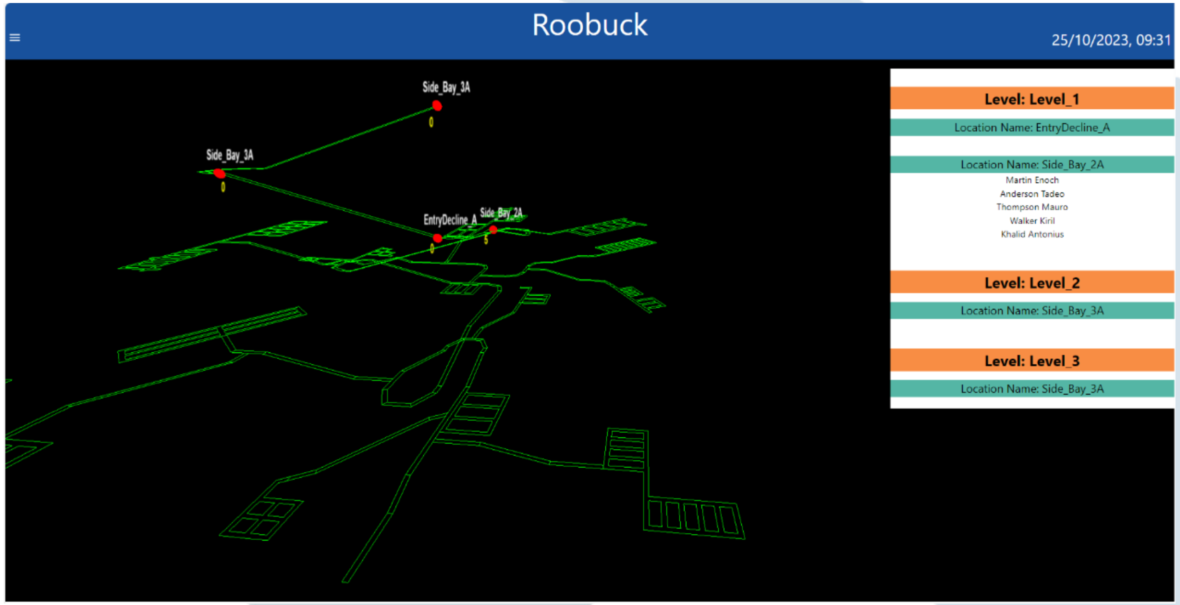
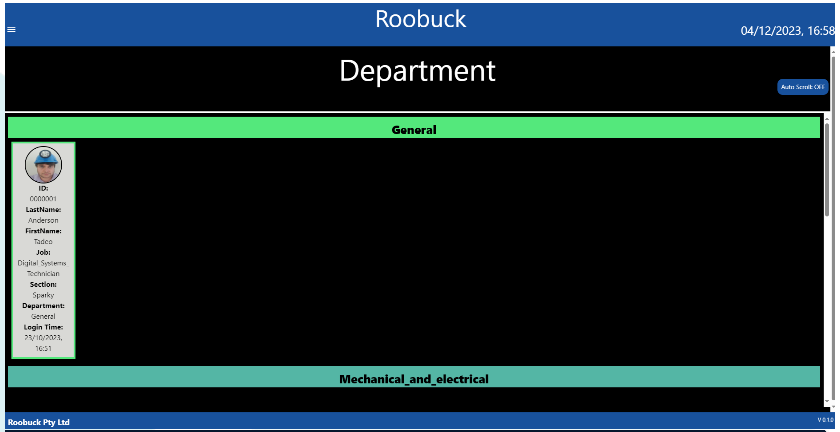
PROJECT UPDATE
DR BINGHAO LI

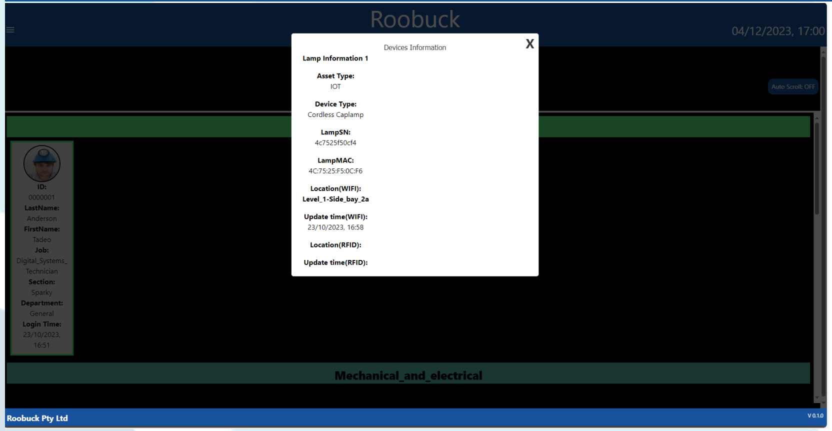
Tag Board

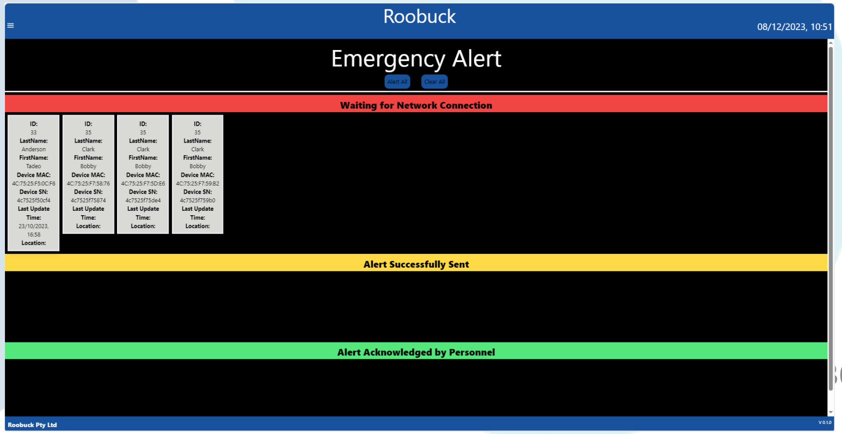
After signing in by Kiosk System, users and devices information will be shown in tagboard. The personal will be tracked by RFID and WIFI. The location information will be shown in tagboard.

After click “Alert All” button, MQTT system will send emergency alert to each IOT devices.









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Challenge 1: Low Light Mining Tunnel Environment

Objective: We need to utilize image enhancement algorithms for enhancing and brightening images captured by 2D cameras in low light environments. The purpose of this is to improve the accuracy of the tracking and collision avoidance components in downstream tasks. Brighter images mean higher and clearer contrast, which is a key upstream task for our subsequent tasks.

Zhou, Y., Wong, L.N.Y. Automatic, Point-Wise Rock Image Enhancement by Novel Unsupervised Deep Learning: Dataset Establishment and Model Development. *Rock Mech Rock Eng* **56**, 8503–8541 (2023). https://doi.org/10.1007/s00603-023-03490-1

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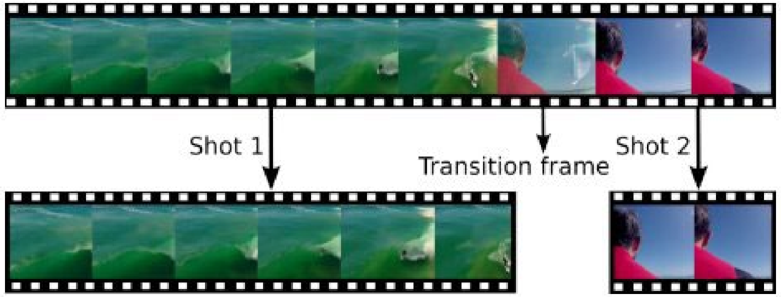

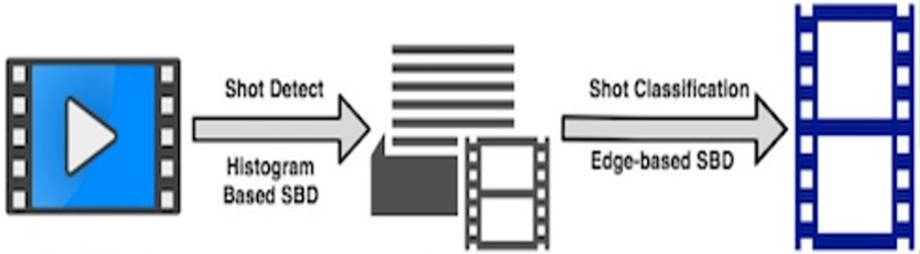

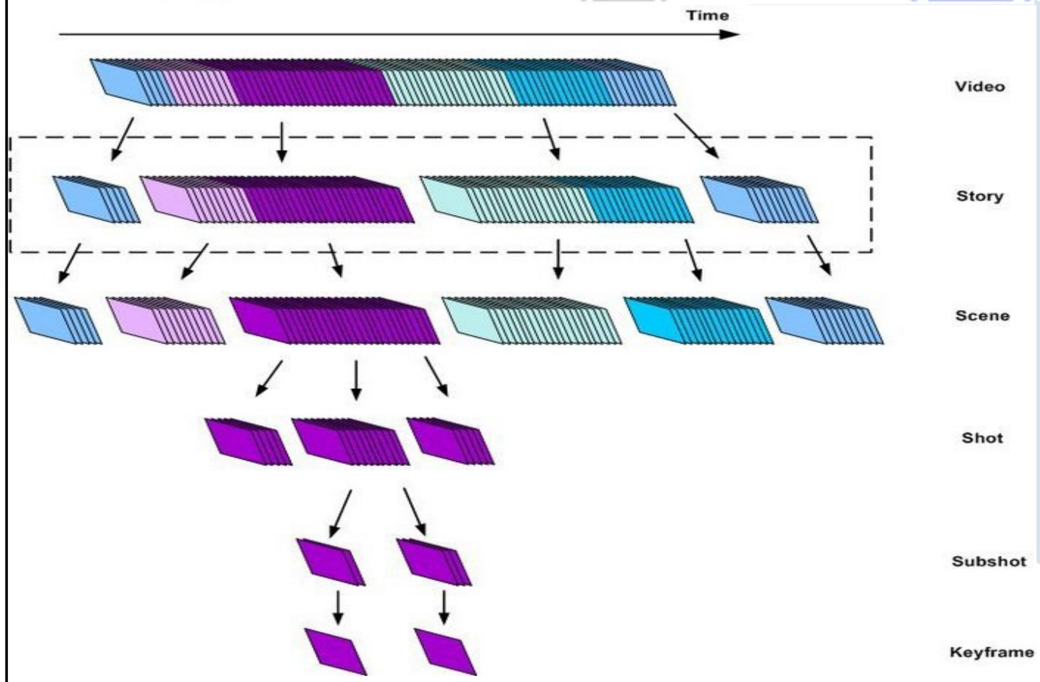

Challenge 2: Tracking in the video

Key Frame Extraction: Identify and extract key frames from the video. These frames should represent significant or changing moments in the video.

Object Detection: Apply an object detection algorithm to identify vehicles within the key frames.

Feature Extraction: Extract features from detected vehicles for tracking.

Tracking Algorithm Implementation: Implement a tracking algorithm to follow the detected vehicles across frames. Use methods like optical flow or more complex association algorithms based on features or machine learning to track vehicles from one frame to the next.

Progress to date:

- Camera image enhancement– using low light enhancement method to brighten the tunnel image (done)
- Classifying and identifying vehicle within the camera footage by visual feature descriptor (done)
- Keyframes and intra-frame image identification from camera shots (undergoing)
- The third step involves designing a similarity image identification algorithm based on the keyframes (undergoing)

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THEME 1 PROJECT

Dr Feng

Underground Navigation and Obstacle Avoidance for Unmanned Equipment

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PROJECT UPDATE
DR BINGHAO LI

CI – Binghao Li	Industry – Azure Mining Technology	Hub Theme 1,2,5

Project Title: Underground Navigation and Obstacle Avoidance for Unmanned Equipment

Motivation: Automation and robotics are the future of the underground mine operation. The positioning, navigation, and control system that can be applied to underground mines is the key, however still in its early stage. There are clear market demands, but full of research challenges.

Aims: Integrate multiple sensors to achieve high accurate positioning, path planning, navigation, and obstacle avoidance for future autonomous operation in an underground mine.

Approach:

- Development of a multi-sensor integration system based on a mobile robot
- Development of underground navigation, route planning and obstacle avoidance algorithm
- Collaborate with industry partner for intensive testing

Progress to date:

- Vector Field based Strategy for Autonomous Subterranean Exploration
- Hardware development, multi-sensor integration including time synchronization

CCTEG

UNSW SYDNEY

RIIS

Highlights:

- Convert the task into collision-free path following within the constrained environment
- Plan the path from the structure of the underground
- Ensure collision-free in the movement phase
- Multi-sensor time synchronization from hardware aspect

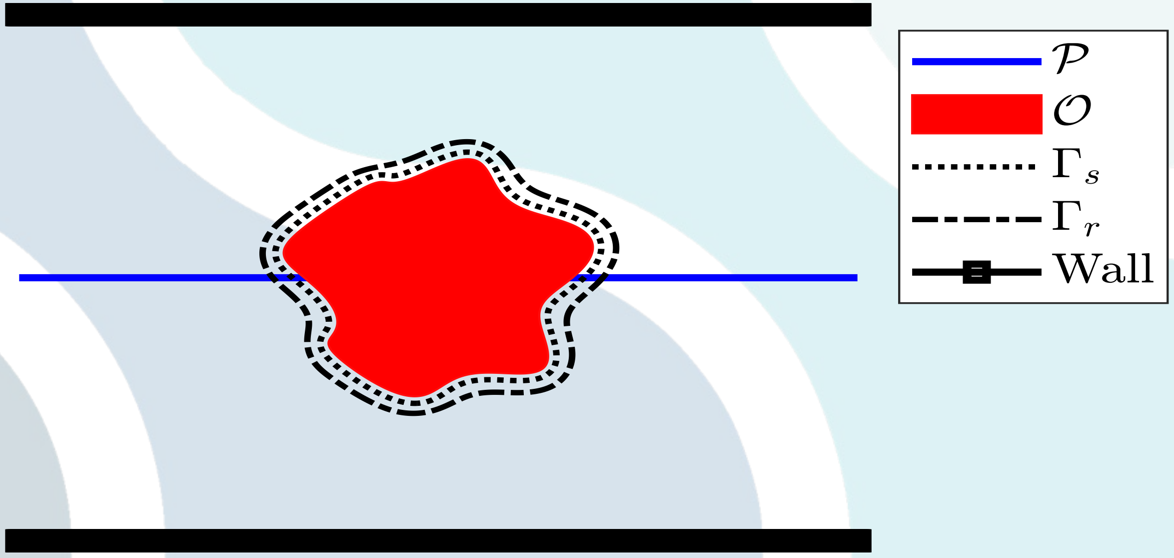
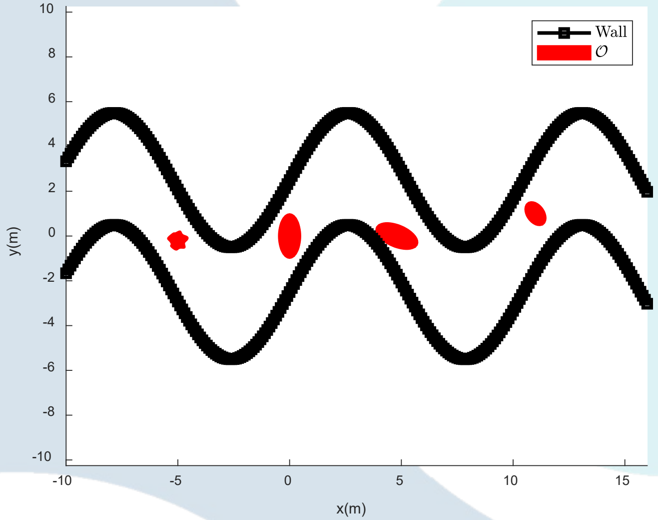


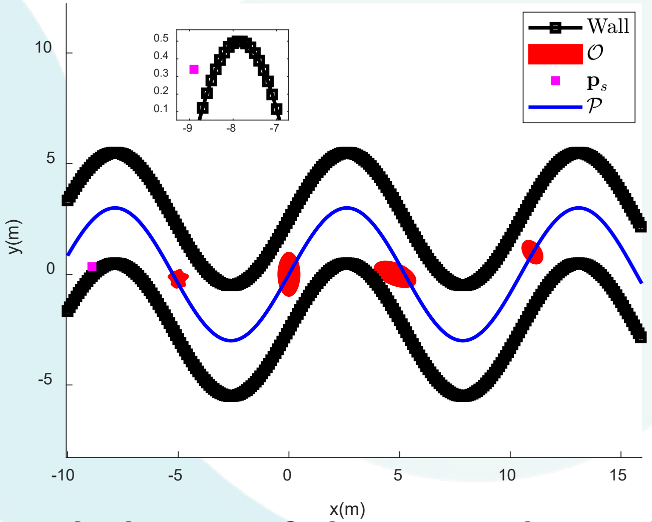
Illustration of the research problem

Technology & Completed design:

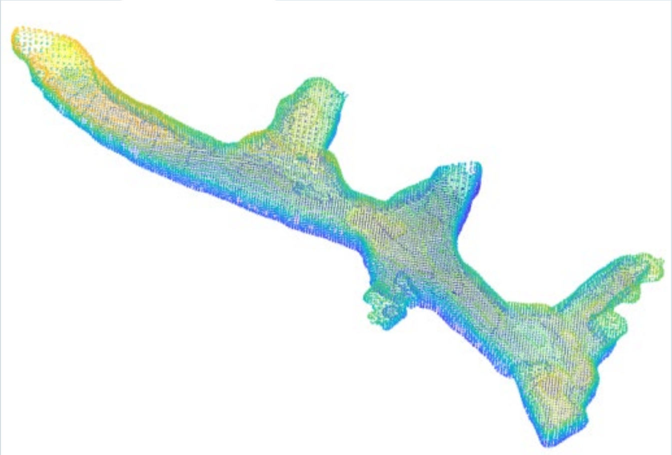
- Environmental skeleton-based reference path generation strategy



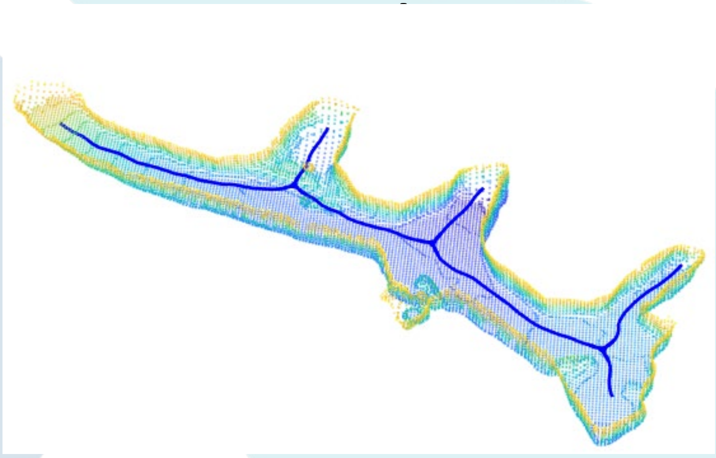
Sine-shaped tunnel



Skeleton of the sine-shaped



Cloud points of a real tunnel



Skeleton of a real tunnel

PROJECT UPDATE
DR BINGHAO LI

Technology & Completed design:

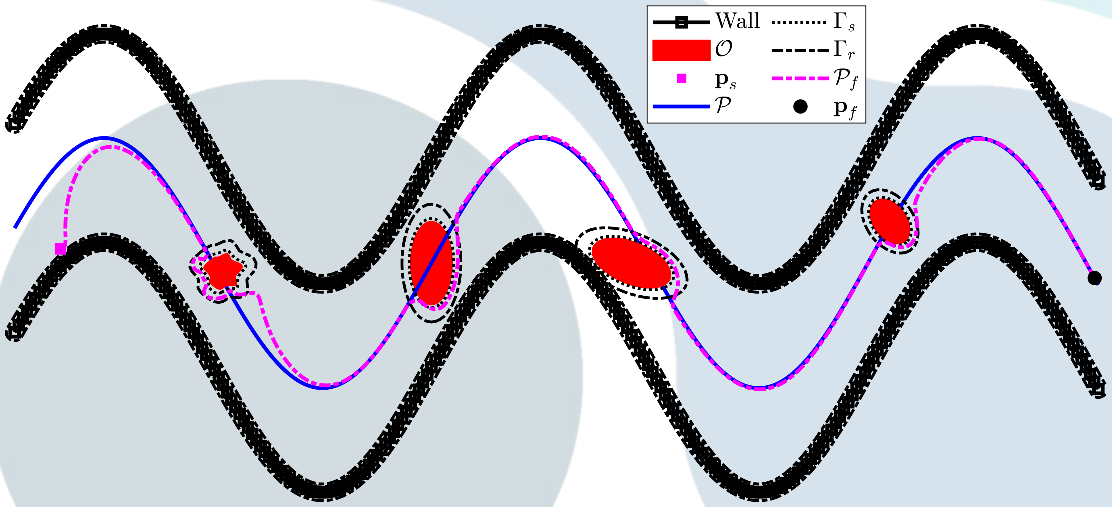
- Vector field-based collision-free path following strategy
  - ✓ Collision-free composite vector field design

$$\chi_c = \alpha\chi_a + \beta\chi_r$$

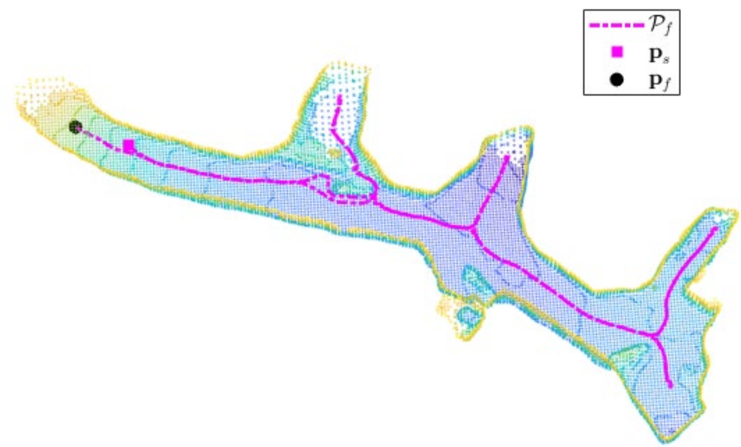
- Path following vector field χ_a
- Converge to the reference path
- Patrol along the reference path

- Collision avoidance vector field χ_r
- Move away from the reference path
- Patrol along the contour of the obstacle

  - ✓ Simulation result



Exploration trajectory in a Sine-like tunnel

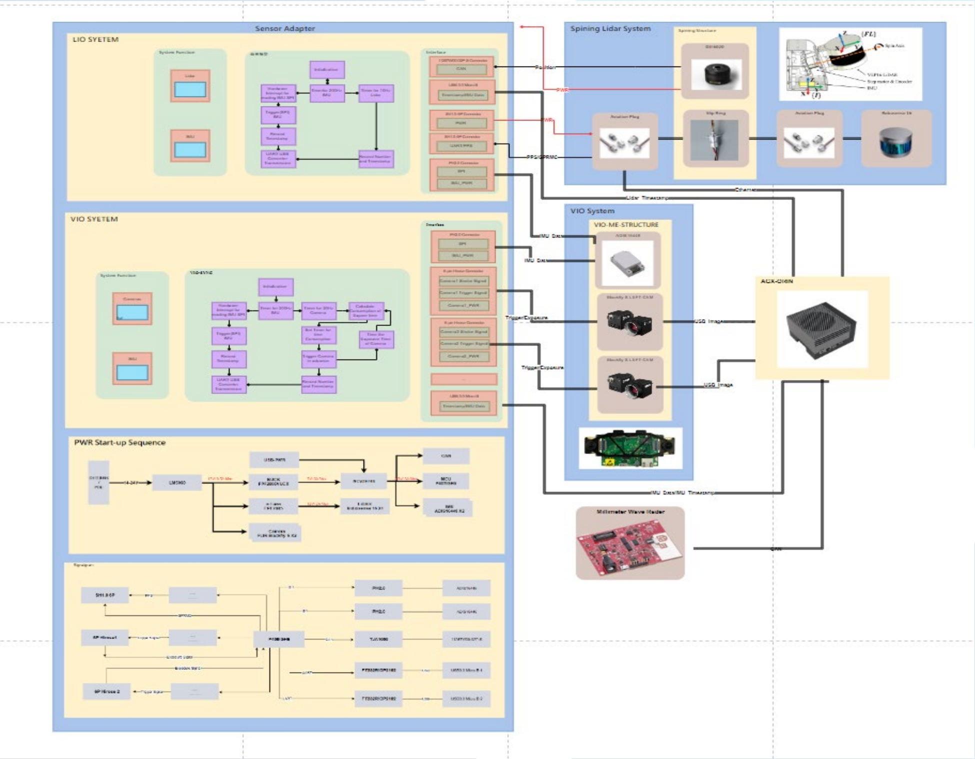


Exploration trajectory in a real tunnel

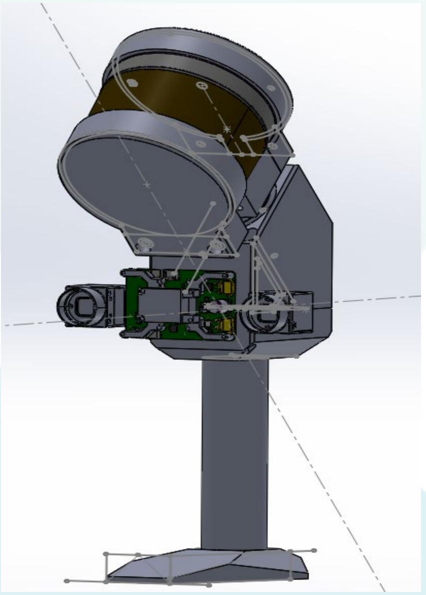
PROJECT UPDATE
DR BINGHAO LI

Technology & Completed design:

- Hardware development



Multi-sensor fusion platform schematic diagram



Structural design of rotating LiDAR with multi-sensors

Professor Chun Wang

Self-powered sensor system for remote condition monitoring

CI –Chun Wang (UNSW)	Industry	Hub Theme 1

Project Title: Self-powered sensor system for remote condition monitoring

Participant: Chun Wang @ UNSW

Motivation:

Self-power sensor systems for condition monitoring infrastructure

- Piles, piers, transmission lines.

Strategies:

- Self-powered sensor coupled with an optical transducer for remote sensing.
- Self-powered IoT sensor with an energy harvester for wireless sensing.

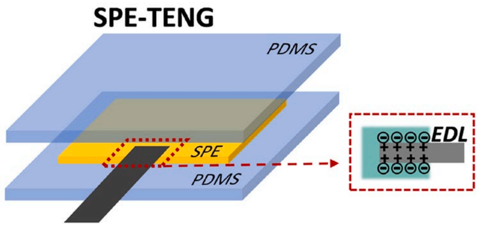
Self-powered or low-energy consumption sensors

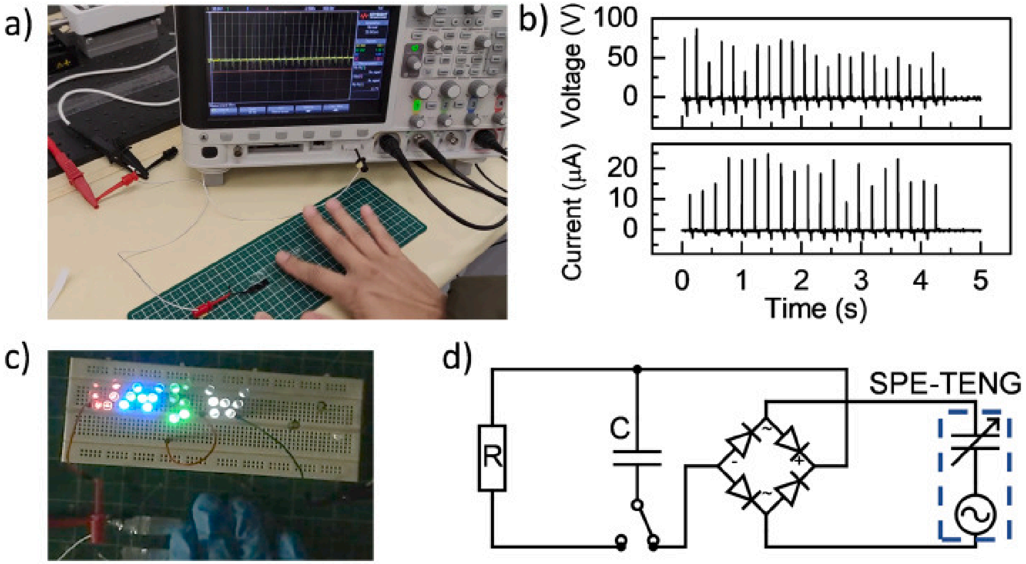
- Low-energy consumption: µW to mW.
- Sensors: vibration, pressure using piezo- and tribo-electric effects.

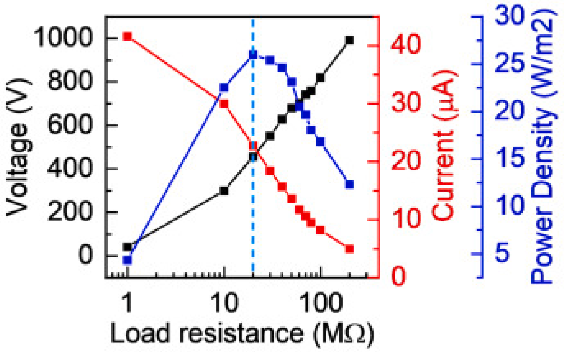
Energy harvesters

- Piezoelectric and triboelectric harvesters for vibration/waves (piles, piers)
- Electrical field, solar, wind (for transmission lines).

harvesting energy from dynamic pressure





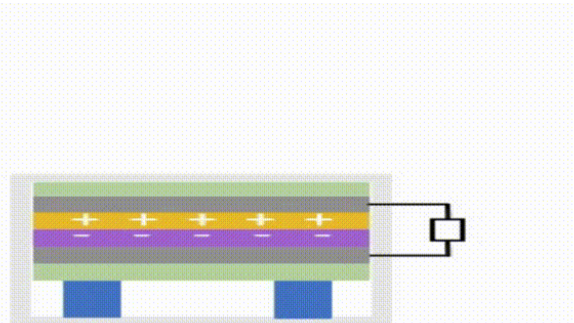


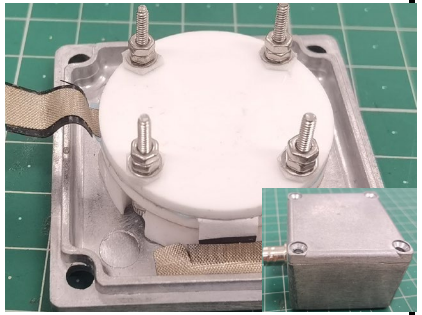
https://doi.org/10.1016/j.nanoen.2021.106289

PROJECT UPDATE
CHUN WANG

Self-powered Vibration Sensor

Clapping vibration sensor





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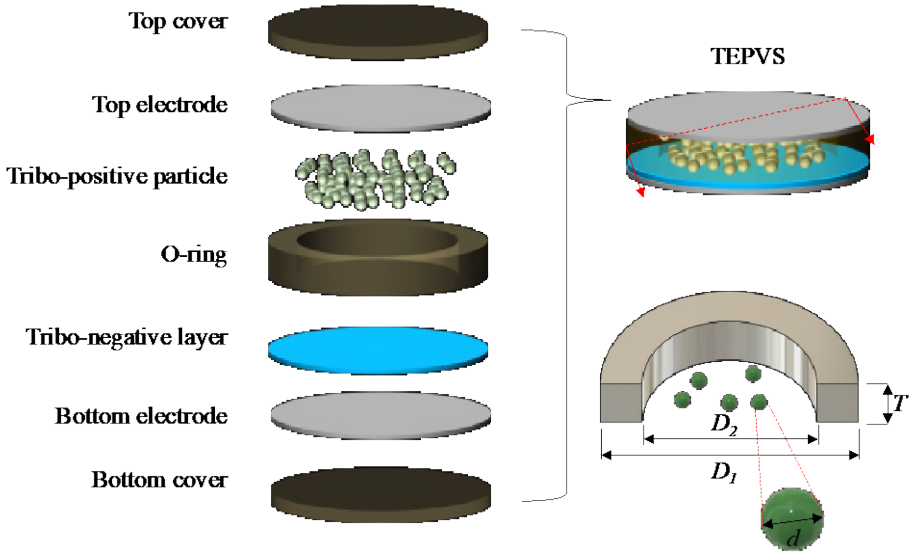
Bouncing particles vibration sensor



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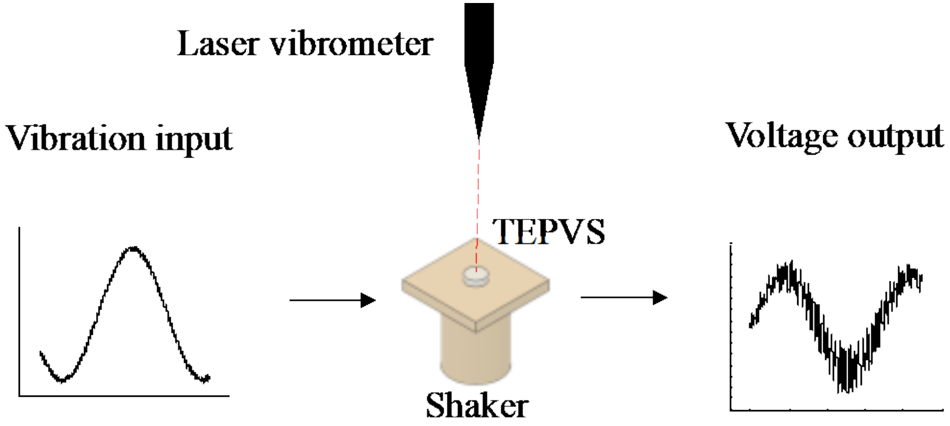
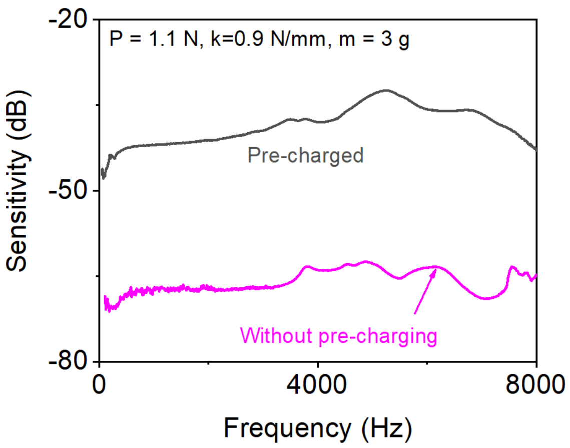
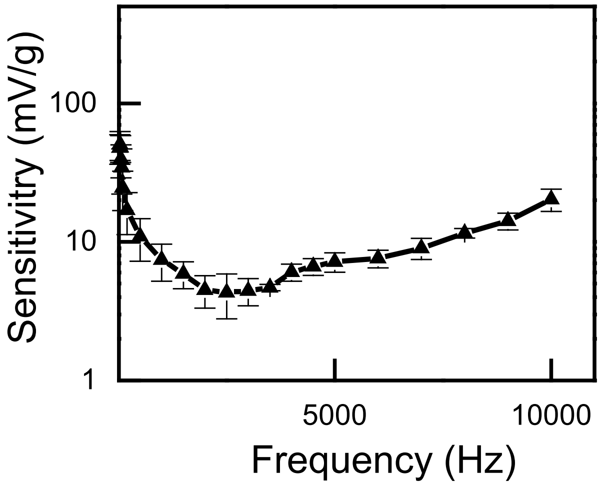
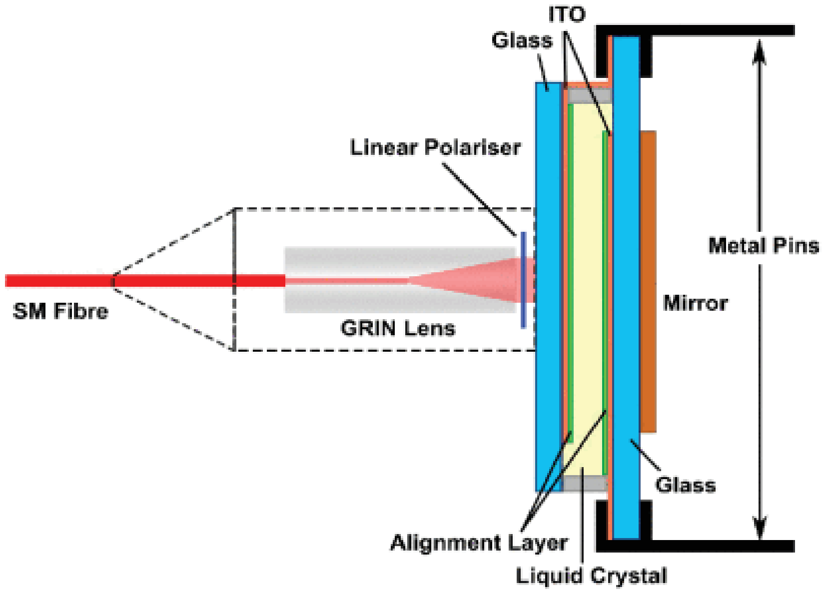
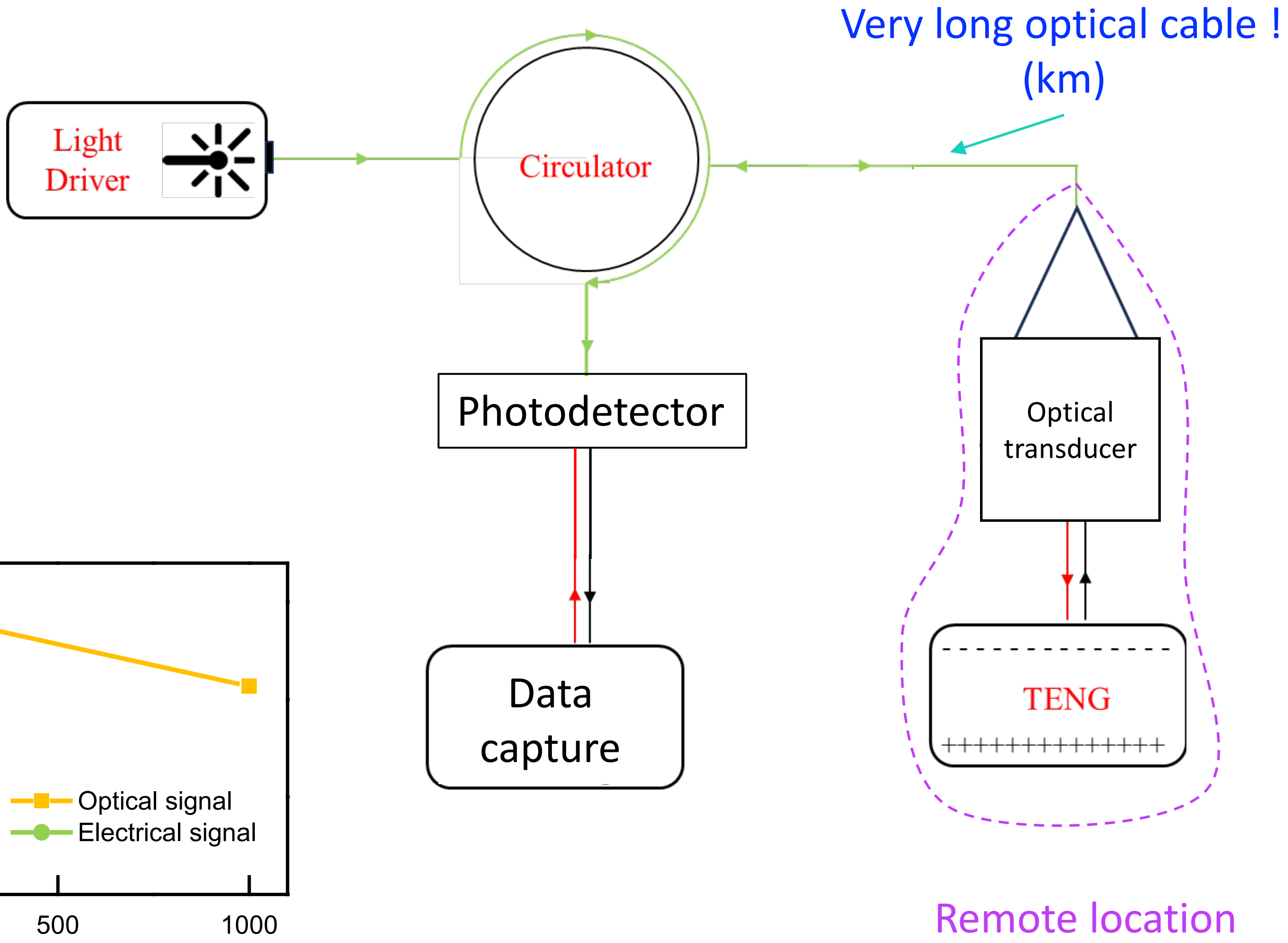


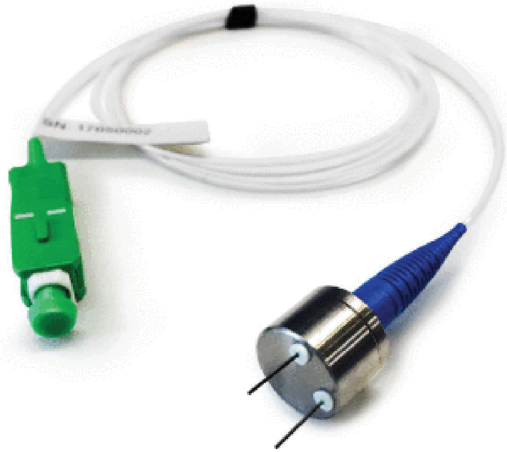


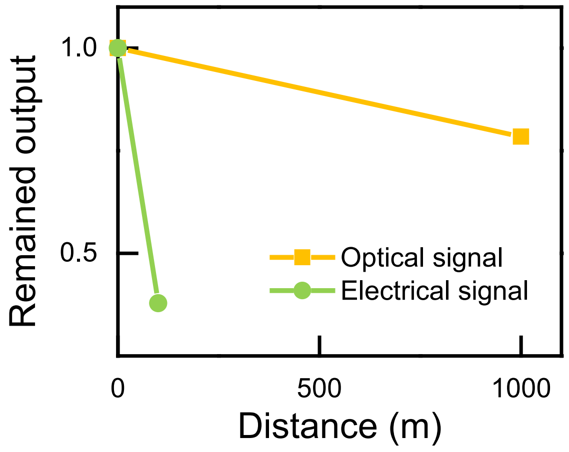


Long distance remote sensing using optical transducer









Opportunities for Hub

1. Self-powered optical-electric sensor
    - Vibration and wave pressure

2. Wireless IoT sensors for transmission lines & tower
    - Vibration harvesters and sensors

Professor Khalili

Real-time characterisation and 3D reconstruction based on photogrammetry, AI and edge computing

PROJECT UPDATE
NASSER KHALILI

CI – A/Professor Stuart Clark	Industry – Kumul Petroleum	Hub Theme 1, 2, 3

Defined – about to commence

Project Title: Real-time characterisation and 3D reconstruction based on photogrammetry, AI and edge computing

Team: UNSW: A/Prof Stuart Clark, Prof Ryan Armstrong, Dr Mohsen Mousavi

Kumul Petroleum: Luke Liria

PhD student is selected, start September 2024

Motivation:

Develop an image-based automated methodology for borehole logging and characterisation including rock quality, fracture system and subsurface layering for reservoir development.

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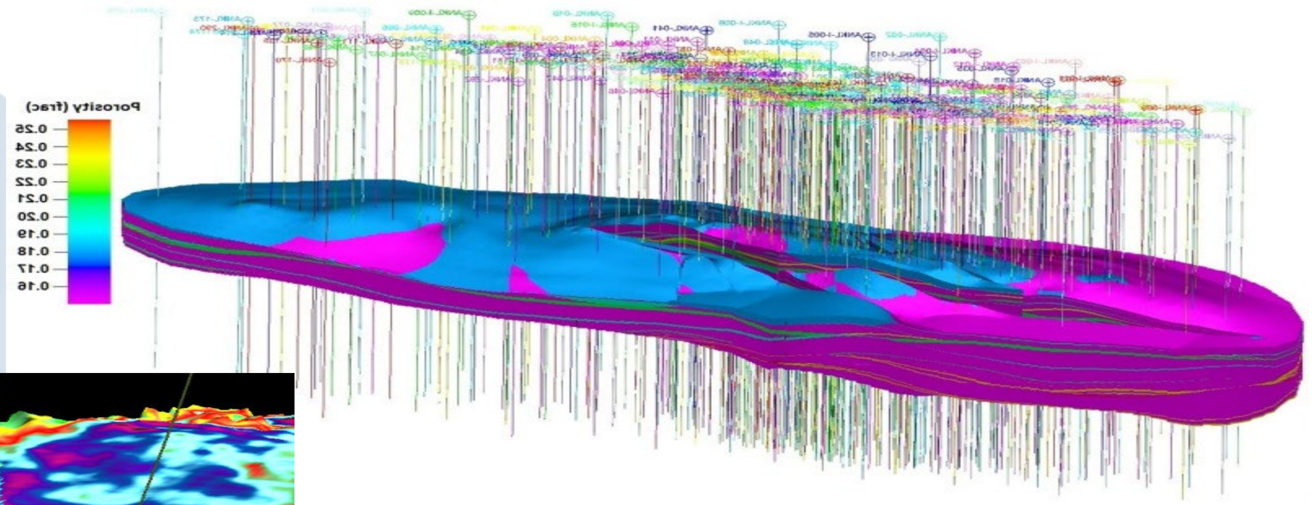
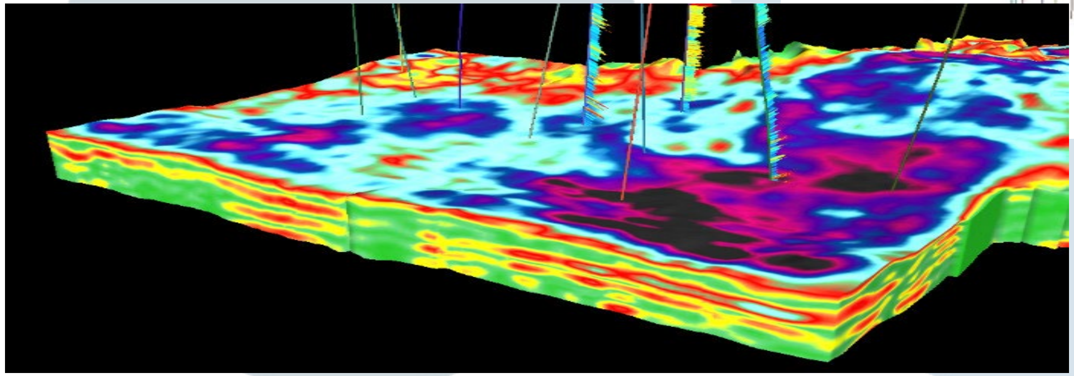
Statement of Problem:

Reservoir characterisation is one of the most elaborate and expensive elements in a reservoir development. It involves extensive borings, exhaustive manual examination of borehole logs, and numerous imprecise testing on disturbed and undisturbed samples.





Aims:

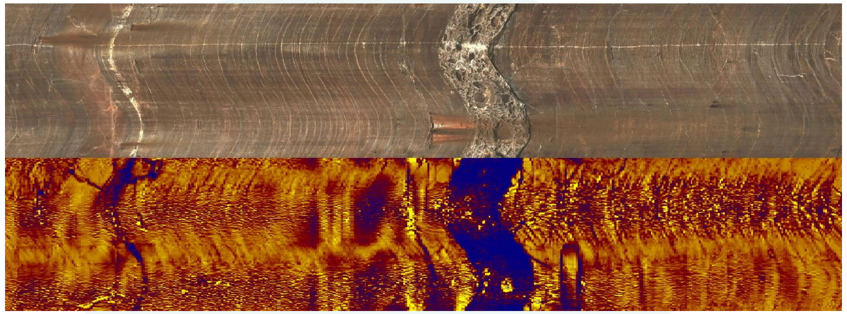
- Provide a low-cost, cutting-edge technology for real-time in situ characterisation of subsurface.
- Enable access to information on lithology, structure and material characterisation in an undisturbed state.
- Identify flaws/structure/formation features and ascertain their properties/impact on the subsurface as well as quantification of their mechanical properties and fluid flow characteristics.

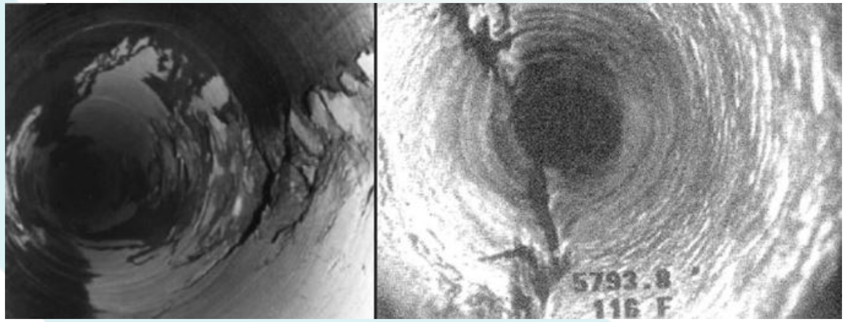
Approach:

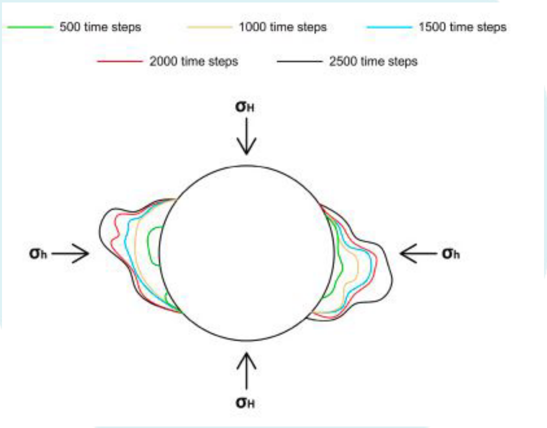
- Analyse downhole optical, acoustic and electrical imaging, coupled with AI/ML to extract features, to identify rock/soil types and their properties and in situ stresses.

- Augment sparse data using physics informed neural network and utilize edge computing for real time analytics.

- Provide 3D digital twin of the subsurface.

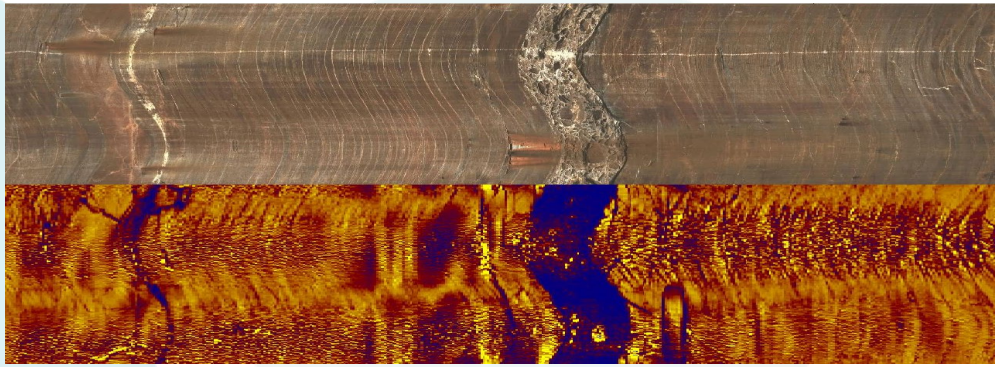


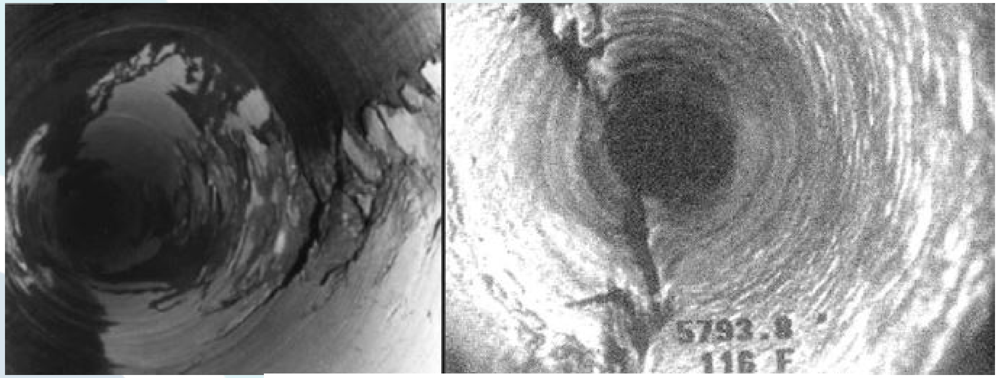


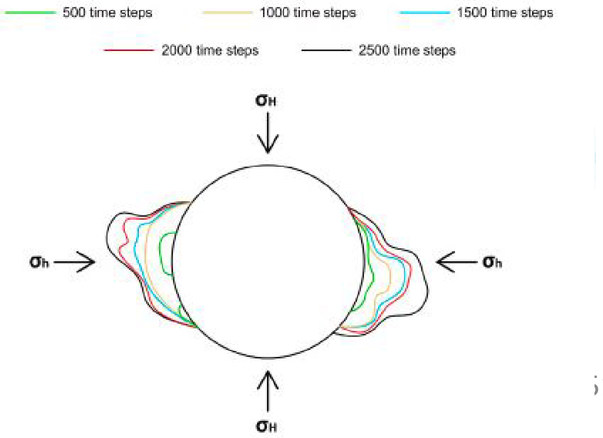


Deliverables:

- A fully validated platform for automated, real time well-log analysis for sparse data
- Subsurface digital twin







THEME 2 LEAD

THEME 2

Data collection, security and integration

Theme 2 Lead

Professor Claude Sammut

UNSW SYDNEY

RIIS

THEME 2 PROJECT

Professor Claude Sammut

Developing Remotely Operated Submersibles for Pier Defect Detection and Integrity Assessment

CIs – Claude Sammut	KUMUL PETROLEUM	Hub Theme 2

Project defined – yet to commence

Project Title: An autonomous submersible for condition monitoring of piers and bridges

Involved:

UNSW: Will Midgley, Claude Sammut

UTS: Dikai Lu (collaboration under discussion)

Motivation:

To address the need for regular inspection and maintenance of piers in adverse conditions

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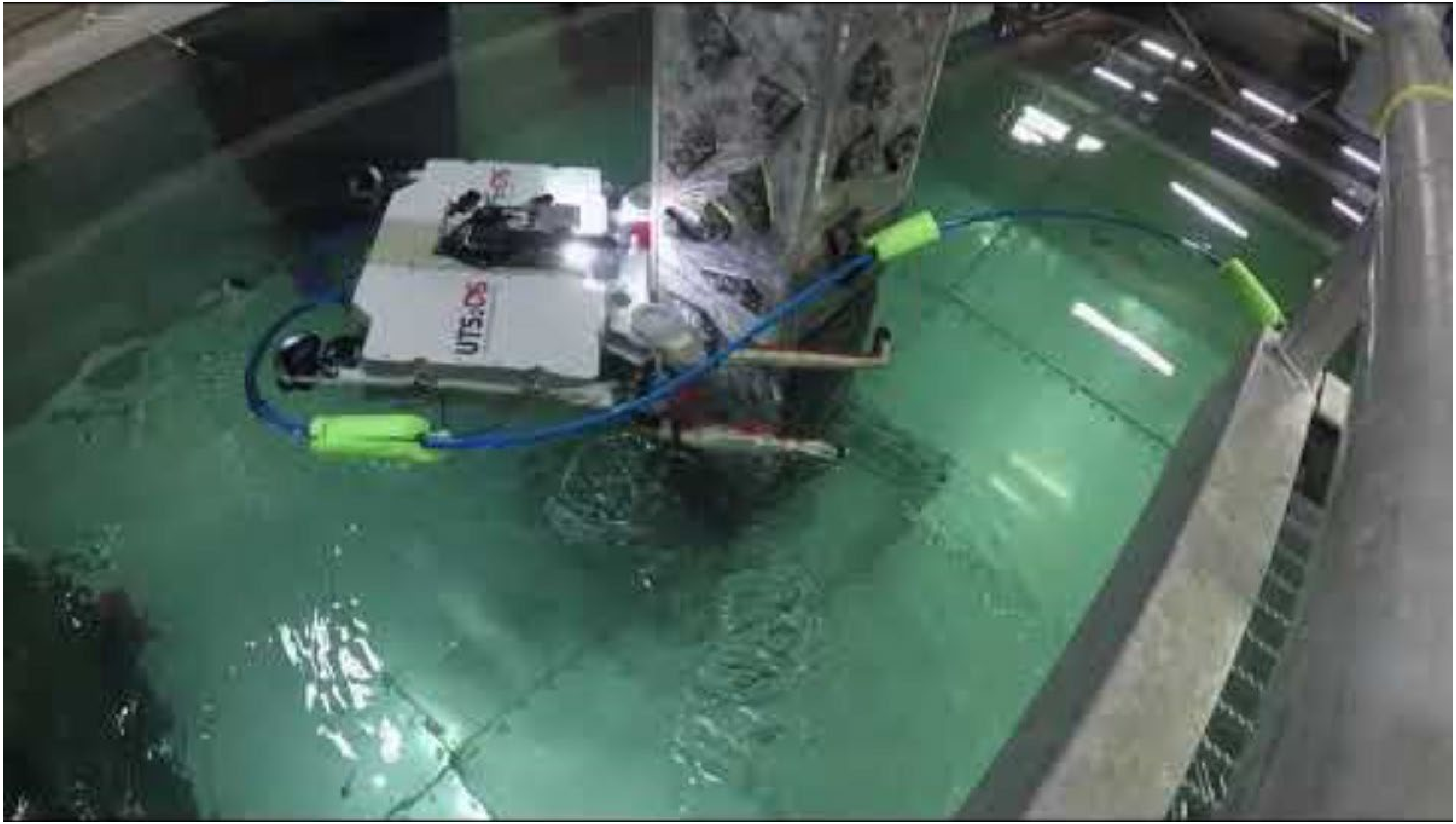
Problem definition:

Autonomous inspection of submerged supporting structures to identify faults and assist in maintenance

Currently done by divers – dangerous and error prone

Aims:

- Develop an autonomous underwater vehicle for inspection and maintenance (in collaboration with UTS Robotics Institute)
- Provide data for digital twins to model corrosion



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Approach:

- Underwater vehicle specification and design
- Sensor/actuator development and selection
- Control of underwater vehicle and inspector hardware
- Data collection and processing

Deliverables:

- Prototype underwater vehicle
- Scanning and data collection software

Professor Peyman Mostaghimi

A Digital Technology for the Characterisation of Oil/Ore Grade and Distribution in a Rock Core

CI – Professor Peyman Mostaghimi	Kumul Petroleum	Hub Theme 2 & 3

Project defined – yet to commence

Project Title: 3D Digital Core Characterisation and Classification of Grains

UNSW: Professor Peyman Mostaghimi, Scientia Professor Nasser Khalili

PhD position advertised.

Motivation:

To address the issue of mineralogical heterogeneity required for high-fidelity core characterisation and porous media simulation

Problem definition:

The current digital core methods fail to capture the presence of various minerals within grains, despite their significant importance for mechanical and flow characterisation and simulation.

Sample Preparation

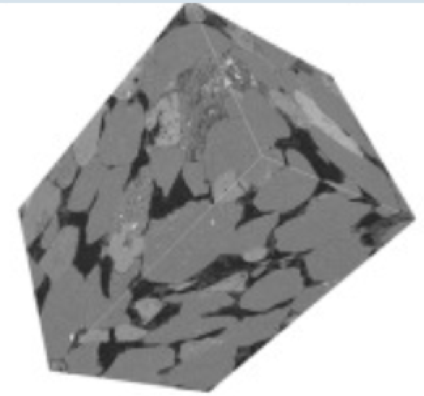
- Sample collection
- Diameter between 5 mm to 100 mm

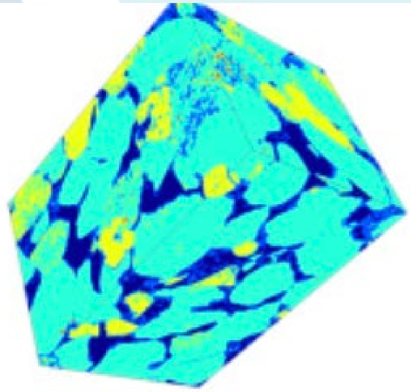
X-ray Imaging and Analysis

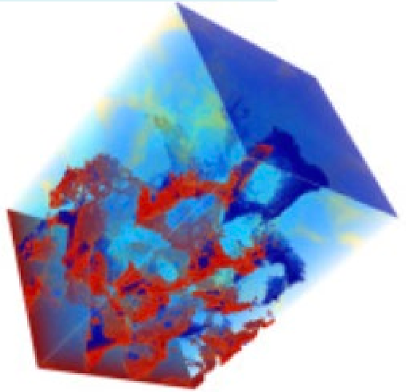
- Generation of grey-scale image
- Multi-mineral segmentation

Upscale Core Characterisation

- Fluid flow
- Mechanical properties







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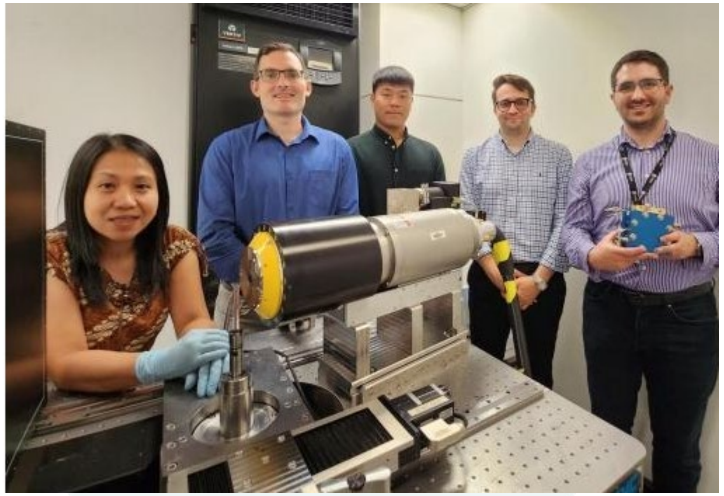
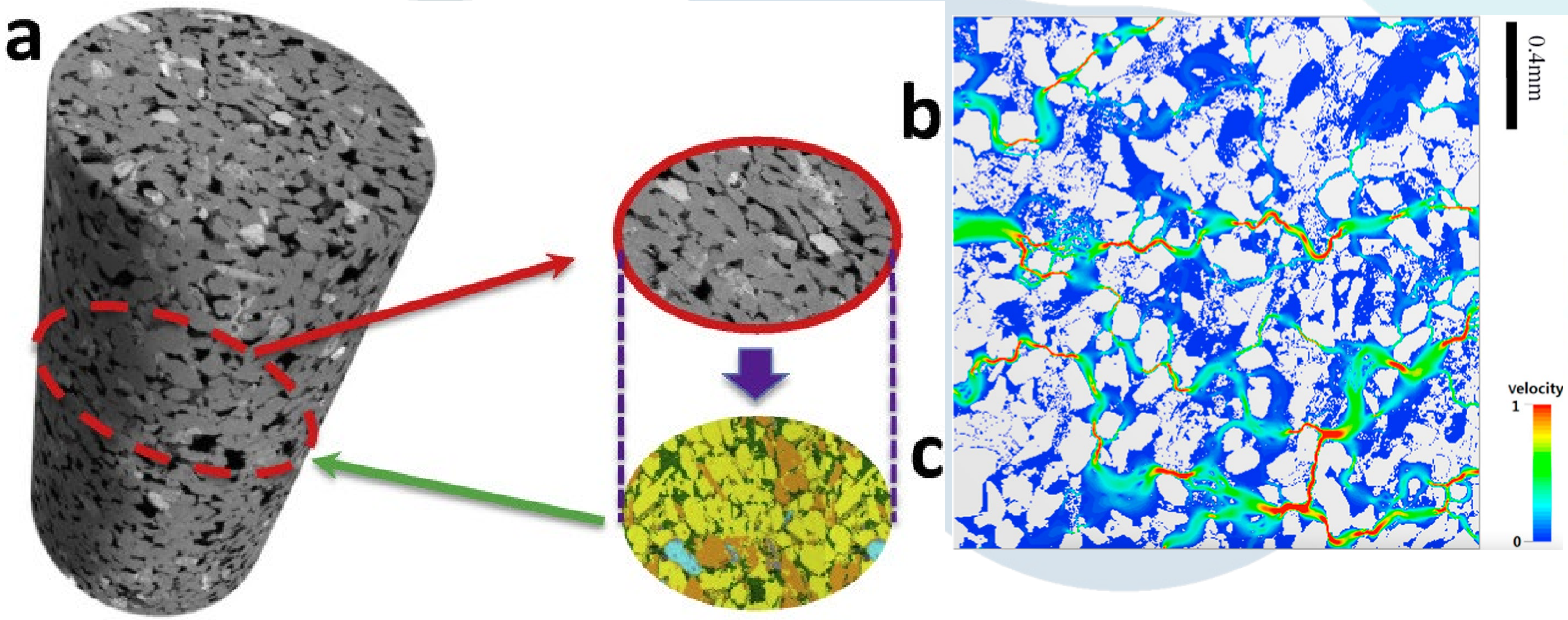
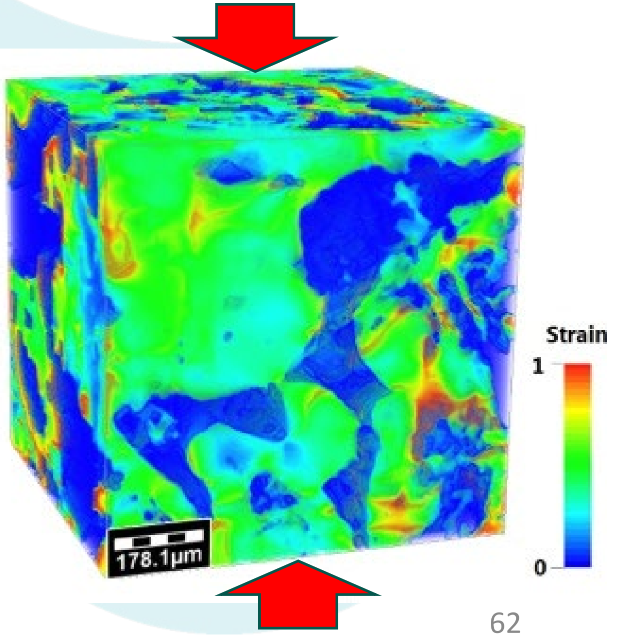
Aims:

- Identify minerals on X-ray images
- Coupled flow experiments
- Validation of results
- Reliable prediction of permeability, porosity and mechanical characteristics of porous sample



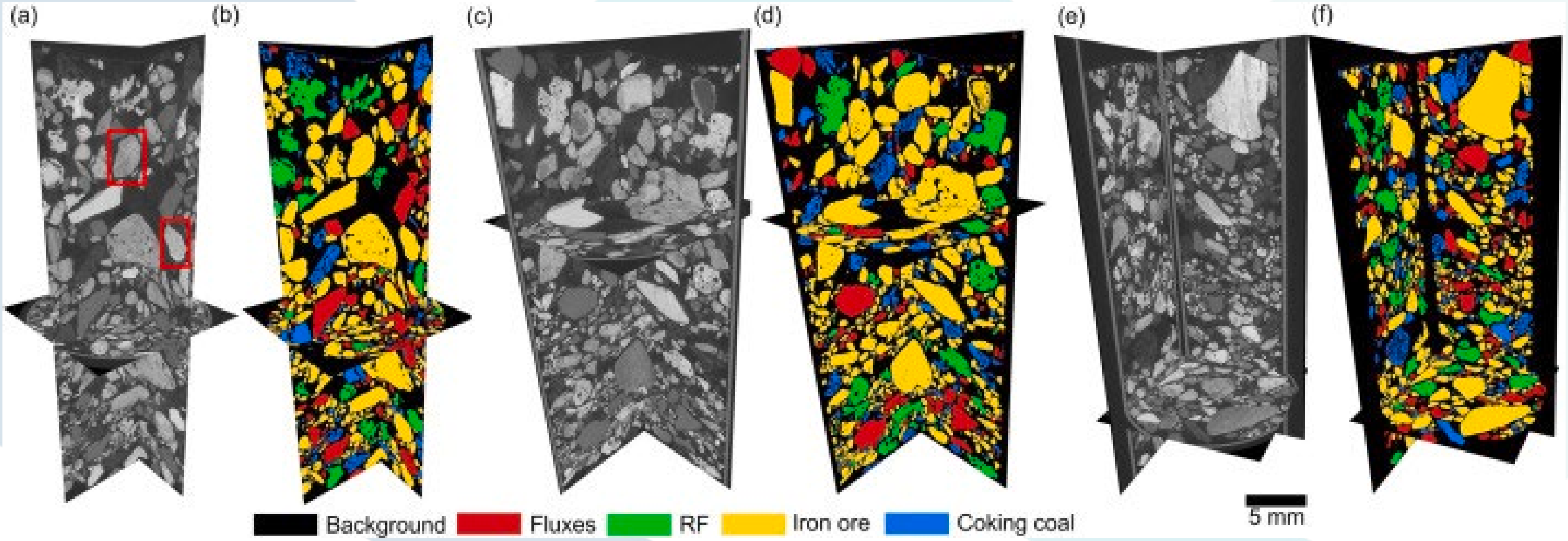




PROJECT UPDATE
PEYMAN MOSTAGHIMI

Our previous works:
application to iron ore sinter green bed | application to reservoir rock

Grey-scale images: output of X-ray scanner | Coloured images: output of CNN method

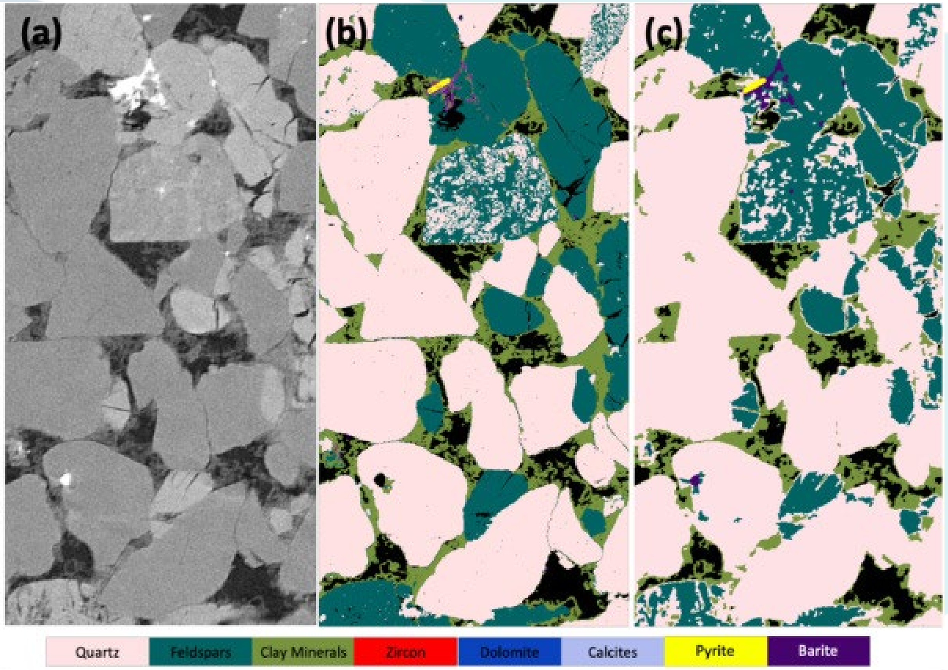


(a) Output of X-ray CT scanner

(b) Output CNN

(c) Output of QEMSCAN

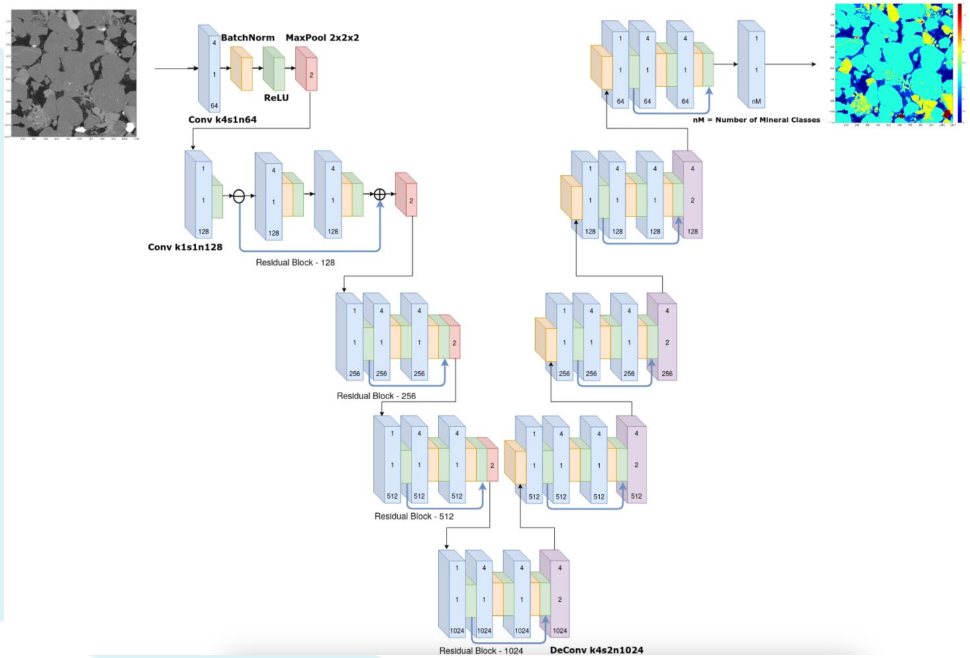
≈95% accuracy

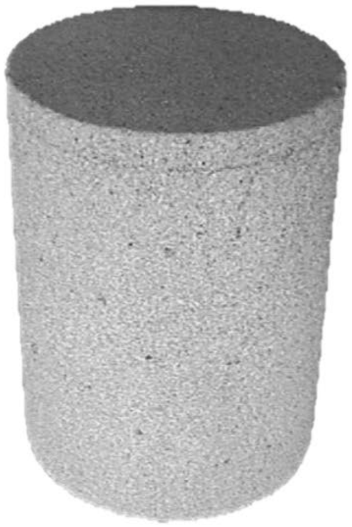


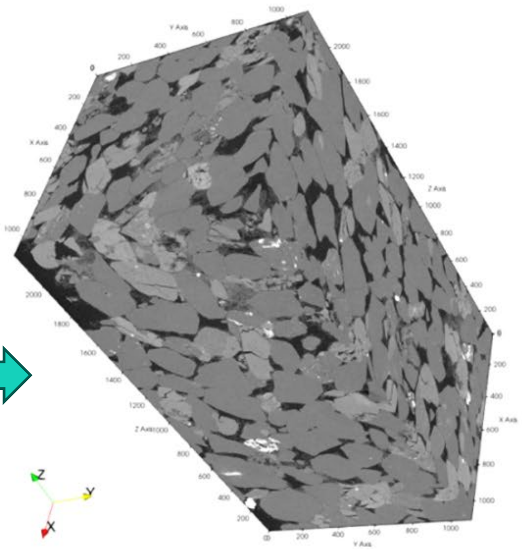
PROJECT UPDATE
PEYMAN MOSTAGHIMI

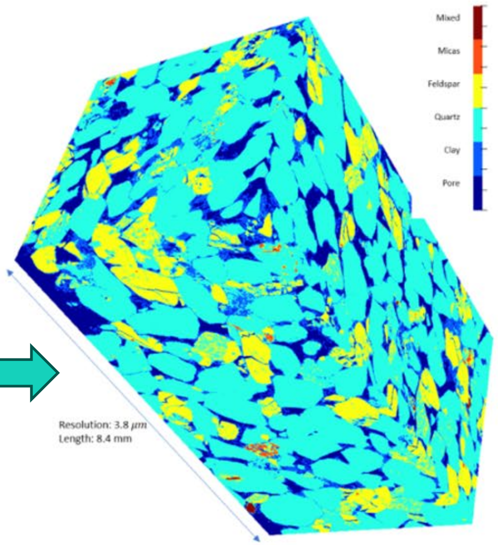
Approach:

Data collection → AI training and testing → Identification of grains → Detailed numerical simulation → Validation → Prediction of flow and mechanical properties of core









Wettability

Young's modulus

Porosity

Permeability

Capillary Pressure

THEME 3

Modelling, simulations and prognostics

Theme 3 Lead

Professor Nasser Khalili

THEME 3 PROJECT

Qihan Wang

Development of computational tool for data-driven structural safety assessment and service life prediction

PROJECT UPDATE
WEI GAO

CI – Professor Wei Gao	Industry – Lindenbaum	Hub Theme 3

Project Title: Development of computational tool for data-driven structural safety assessment and service life prediction

Motivation:

A wind turbine collapsed at the Alinta wind farm in Western Australia - causing the 89MW project to be temporarily shut down

https://reneweconomy.com.au/wind-turbine-collapses-in-serious-event-at-wa-wind-farm/

- Inherent uncertainty
- Higher frequency
- Serious consequence

(human life, wealth, social impact, etc.)

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PROJECT UPDATE
WEI GAO

Gaps in knowledge:

	Static / Dynamic	Nonlinear	Uncertainty	More Complicated
ANSYS	✓	✓	✗	✗
ABAQUS	✓	✓	✗	✗
Strand7	✓	?	✗	✗
COMSOL	✓	?	?	✗

Challenging to Existing Tools

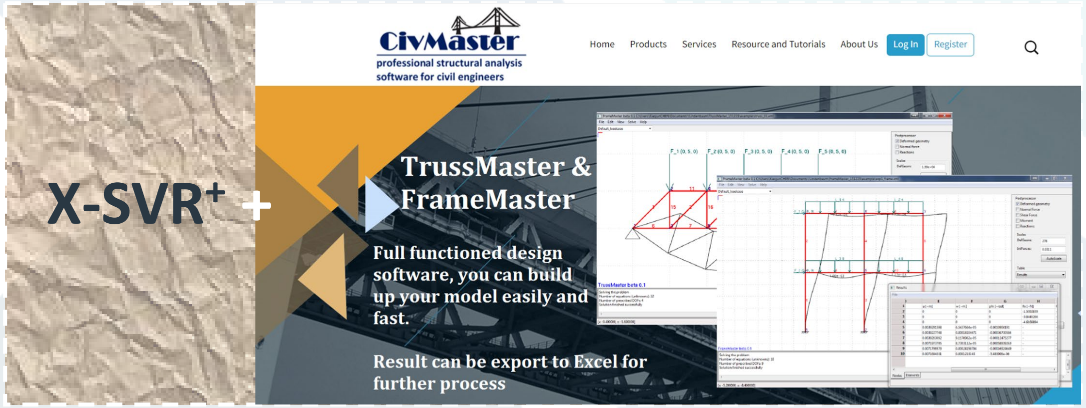
Lindenbaum
RIIS

Aims:

- Develop an advanced tool underpinned by a *virtual reality modelling technique*
- Safety assessment and Service life prediction
- Contribute to build a more *Sustainable*, *Safe*, and *Efficient* Australia

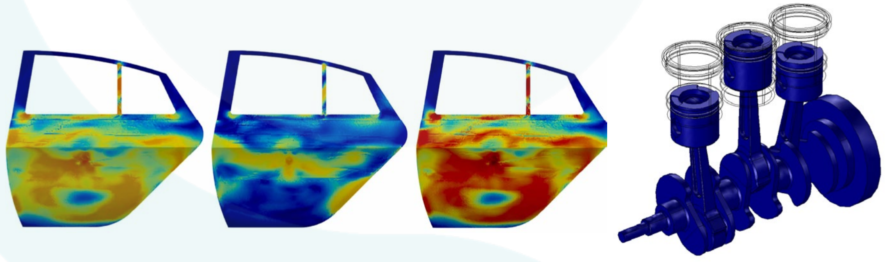
Expected outcomes:

Virtual-Reality Interactive Analysis Framework

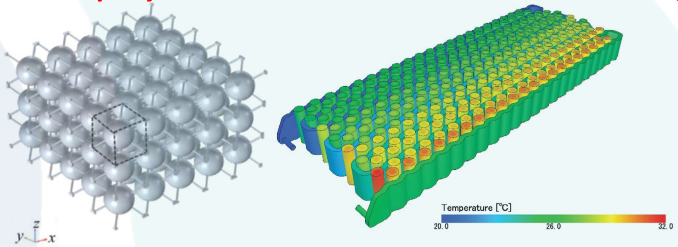


FEM Software CivMaster developed by Lindenbuam
https://www.civmaster.com.au/

Nonlinear /Static / Dynamic / Fracture



Multiphysics / Multi-scale Modelling



Material-Geometric Polymorphic Uncertainty

Alignment with RIIS:

★**Theme 3:** Modelling, Simulations and Prognostics

✦**Theme 4**: Infrastructure health monitoring and predictive maintenance

✦**Theme 5**: Spatial data infrastructures, digital twin and decision support

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Scientific Approach
Virtual-Reality Interactive Analysis Framework

- Multidisciplinary /Interdisciplinary applications
- Experiments
- Information and Communication Techniques (ICTs)

Reality

Info. ↔ Info. ↔ Info.

Virtual Space

Numerical Simulation

- Multiphysics /Multi-scale modelling
- Linear/Nonlinear/Static/Dynamic/Fracture

Geometric Model

Material Model

Physics

Environment

• • •

Info.

Analysis

- Displacement /Stress /Forces
- Safety /Reliability
- Risk/ Rest Life Assessment

Diagnosis

Prognosis

Optimization

Inverse Eng.

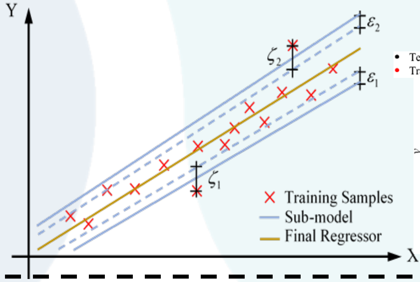
• • •

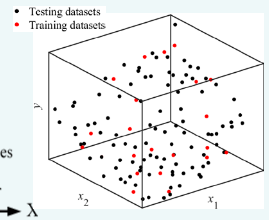
Info.

Info.

Virtual Modelling Technique

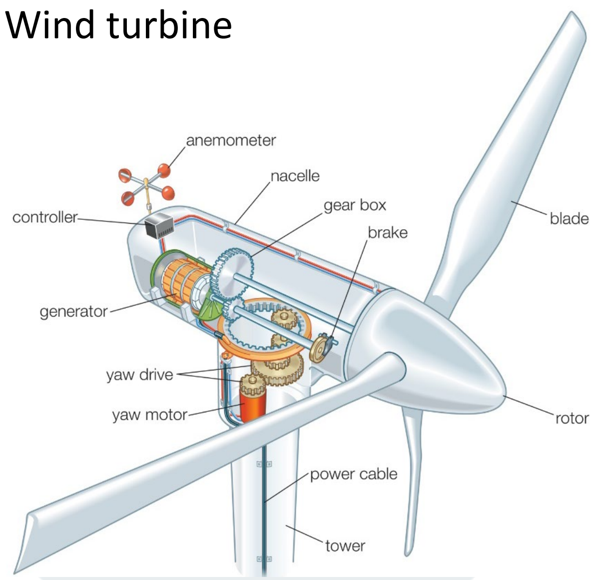
- Machine learning methods
- Cloud/Cluster computing
- Data processing
- Multi-fidelity modelling



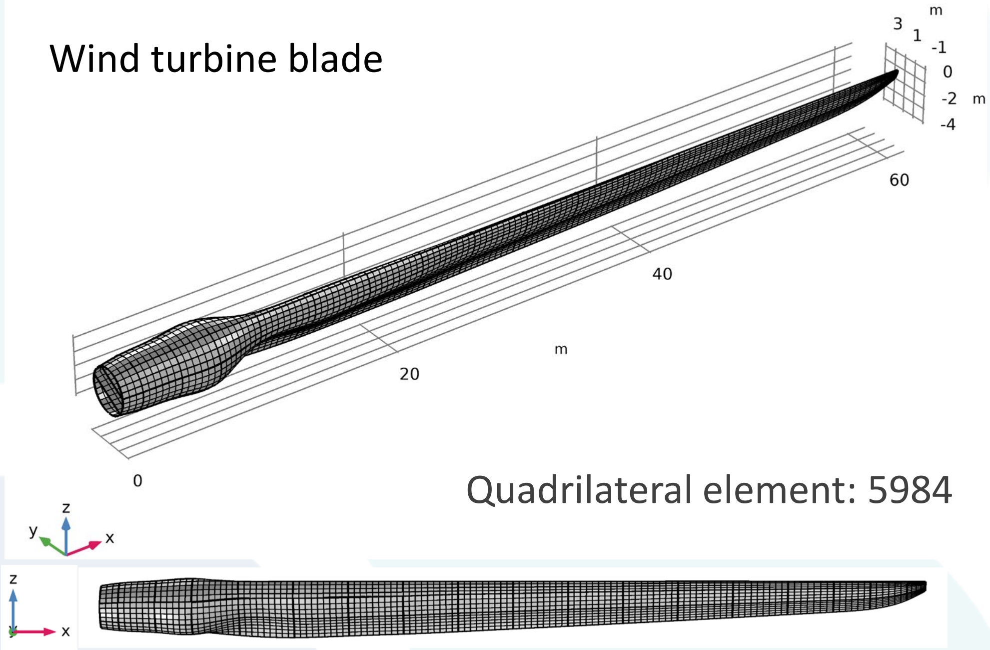


Progress to date: Efficient and powerful machine learning methods have been developed for structural analysis.

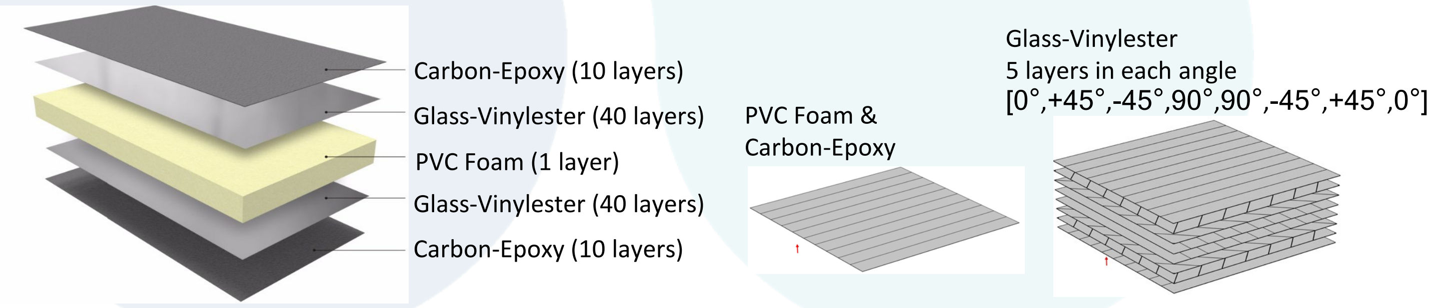
Structure



Analysis – Component

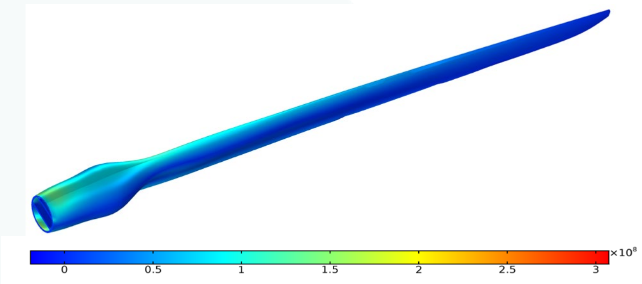


Composite Material



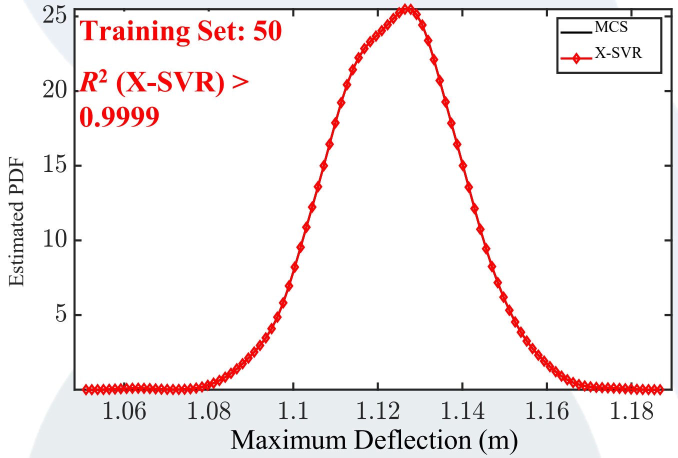
Progress to date: Efficient and powerful machine learning methods have been developed for structural analysis.

Computational Results on Virtual Model

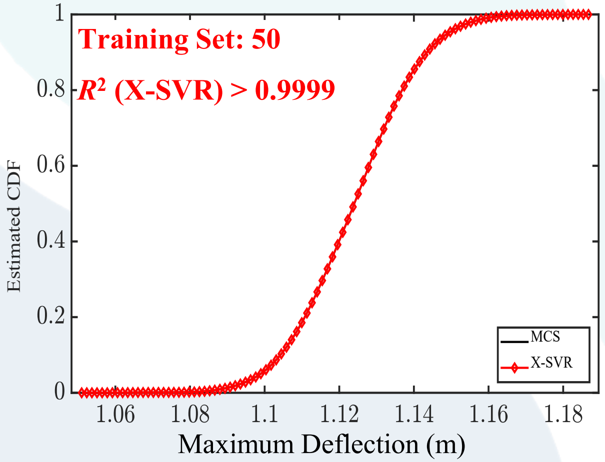


10 System Uncertainties:

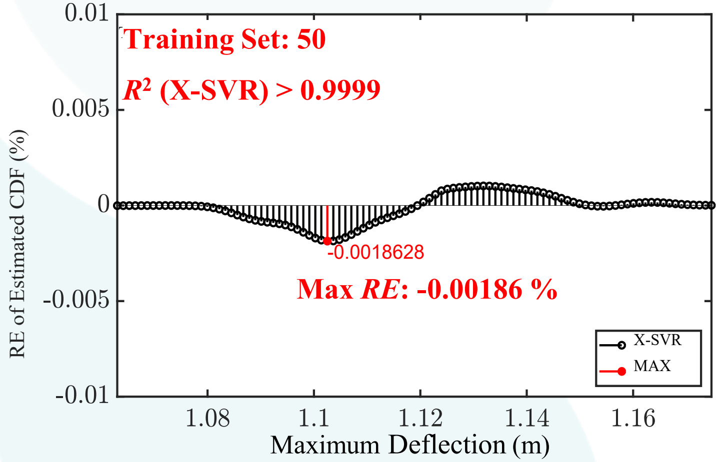
- Rotation speed (1)
- Material properties (9)



(a) Estimated PDF



(b) Estimated CDF



(c) *RE* of the estimated CDF

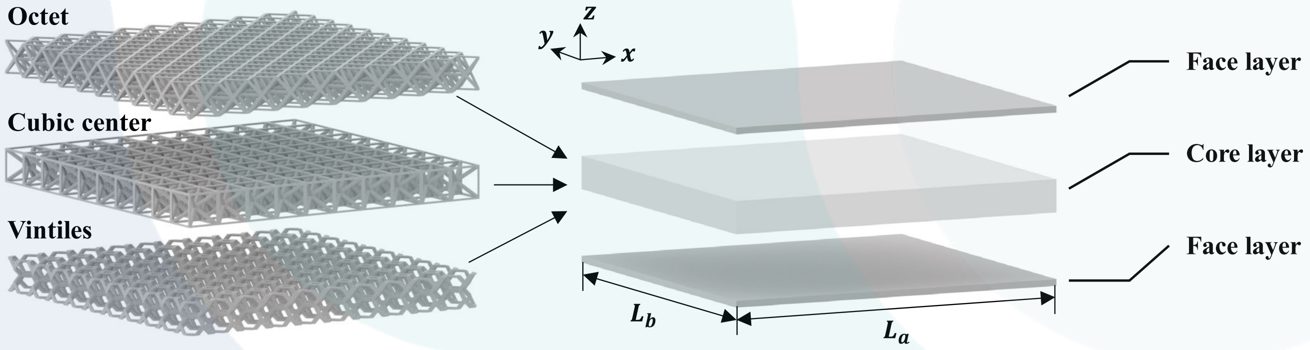
MCS – ***10000*** times FEA
X-SVR – ***50*** times FEA

Efficiency 200 times

PROJECT UPDATE
WEI GAO

Progress to date: Efficient and powerful machine learning methods have been developed for structural analysis.

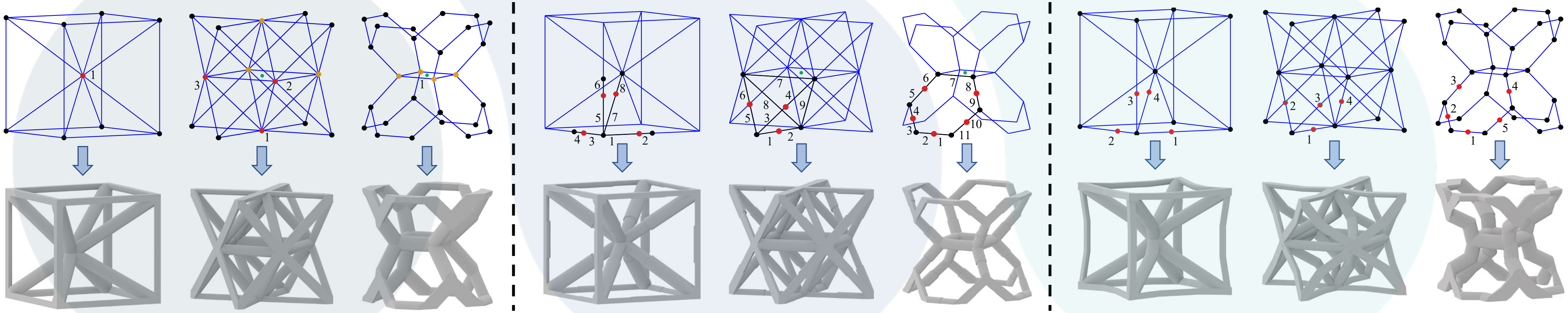
Analysis - Material (Microscale)



Lattice-core composite sandwich plate

Imperfections

Node dislocation | Radius variations | Waviness



Tian, W., Li, Q., Wang, Q., Chen, D., & Gao, W. (2024). Additive manufacturing error quantification on stability of composite sandwich plates with lattice-cores through machine learning technique. Composite Structures, 327, 117645.

Lindenbaum

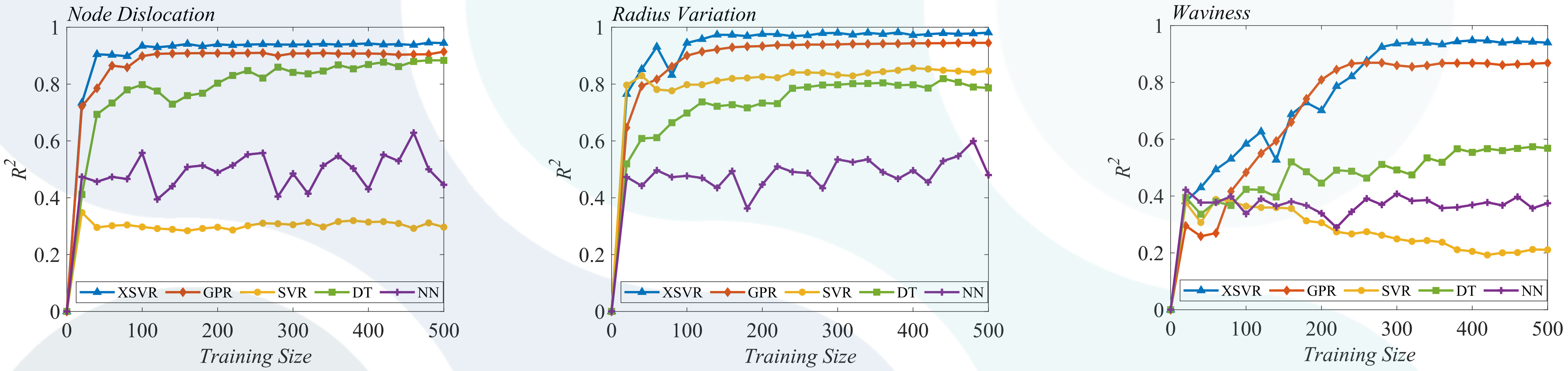
RIIS

PROJECT UPDATE
WEI GAO

Progress to date: Efficient and powerful machine learning methods have been developed for structural analysis.

Analysis – Material

Virtual Model Construction



Fast Convergence* & *High Accuracy

Sensitivity Analysis

Radius variation > Waviness

Static buckling capacity of this product

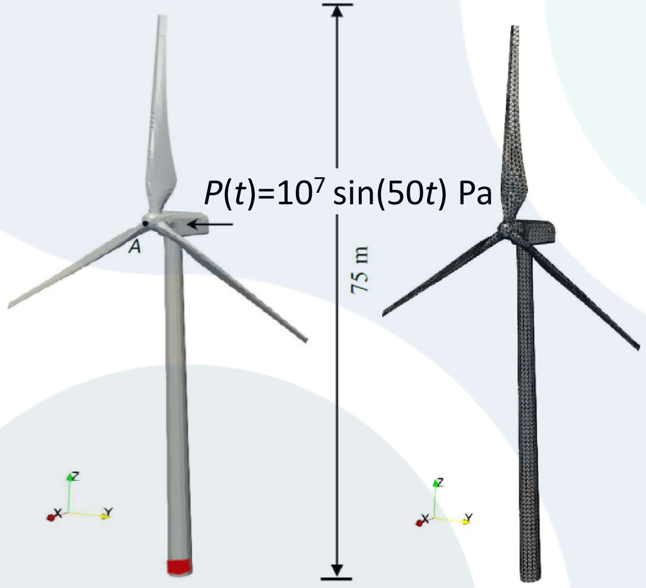
Contribute to the Design Optimization, Manufacturing & Processing

Tian, W., Li, Q., Wang, Q., Chen, D., & Gao, W. (2024). Additive manufacturing error quantification on stability of composite sandwich plates with lattice-cores through machine learning technique. Composite Structures, 327, 117645.

Progress to date: Efficient and powerful machine learning methods have been developed for structural analysis.

Analysis – Structure (Elastoplastic dynamic analysis)

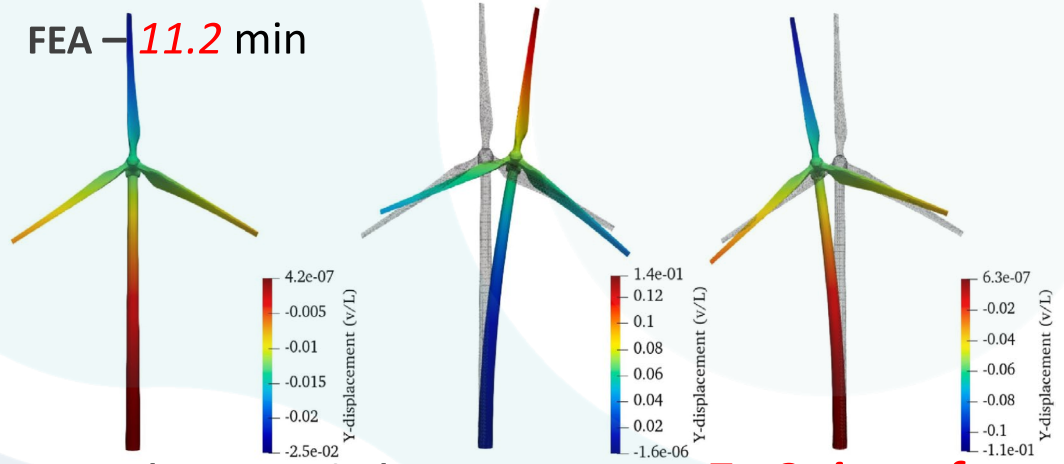
Numerical Model



Tetrahedral element: 18072

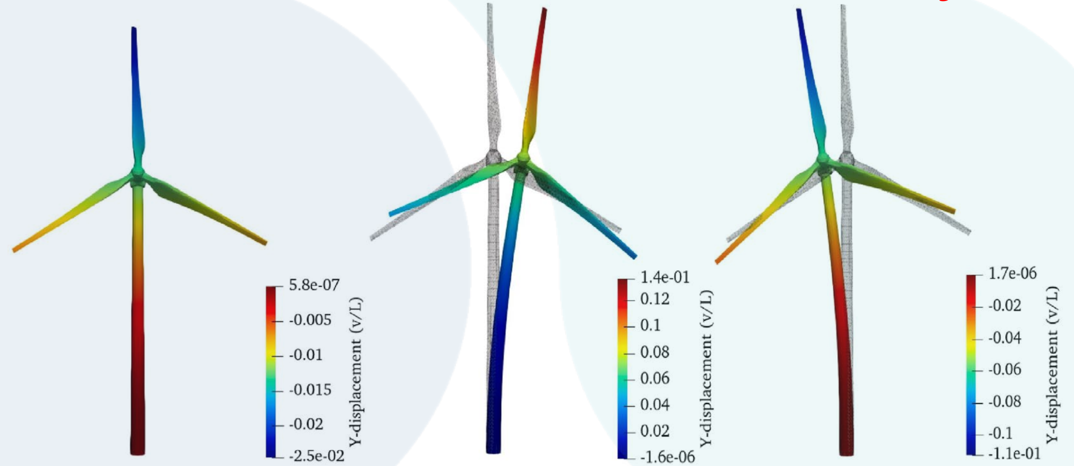
Virtual model construction - 25 min

FEA – 11.2 min



X-SVR (200 Samples) – 1.5 min

7 - 8 times faster interaction



Max *RE*: -0.797% 3.571% -4.464%

Feng, Y., Wang, Q., Chen, X., Wu, D., & Gao, W. (2023). Virtual modelling technique for geometric-material nonlinear dynamics of structures. Structural Safety, 100, 102284.

Progress to date: Efficient and powerful machine learning methods have been developed for structural analysis.

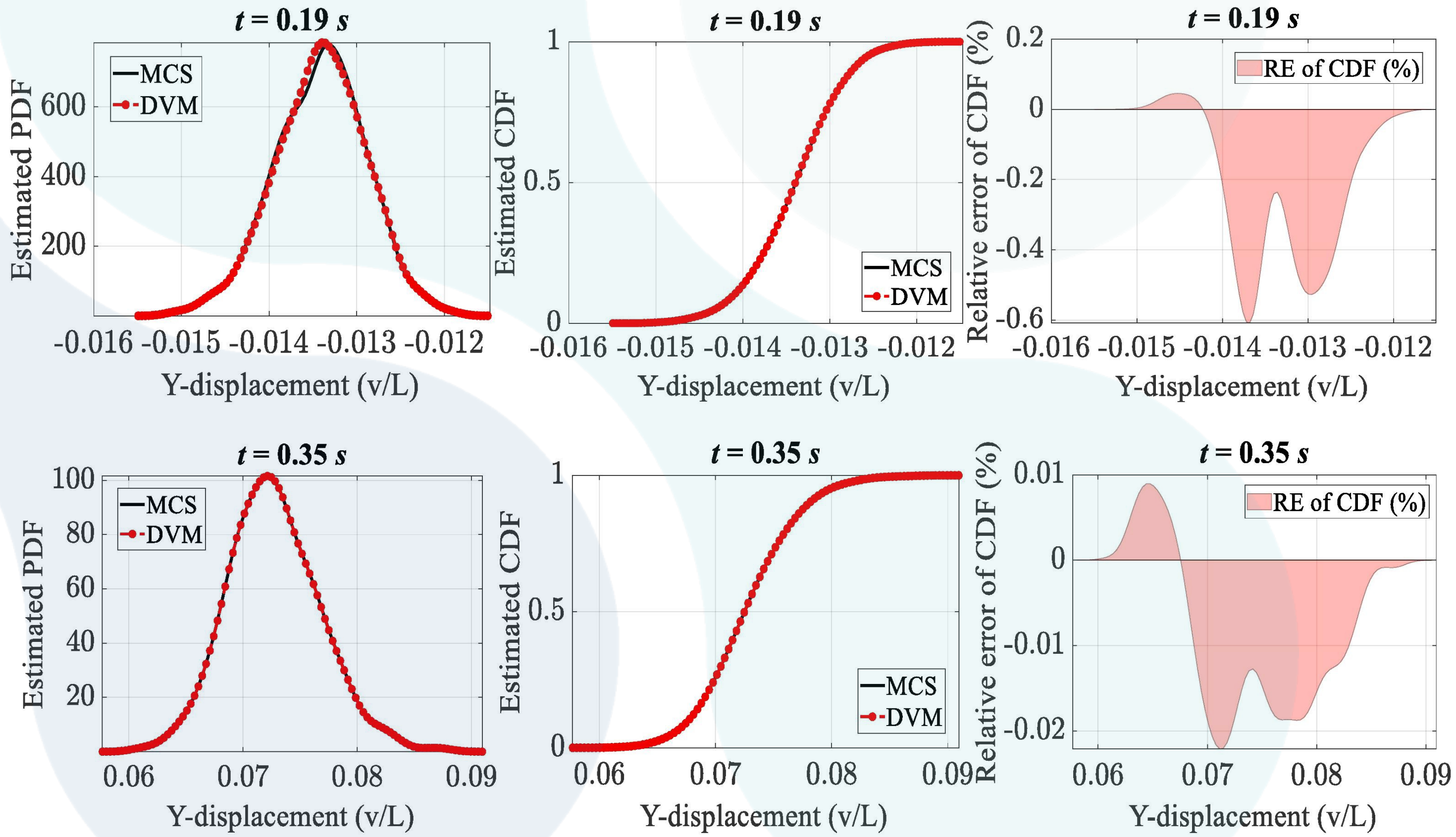
Analysis – Structure (Elastoplastic dynamic analysis)

Sufficient statistical information on arbitrary time spots and locations

System Uncertainty:

- Young's modulus (GPa)
  – Normal
  (mean 206.9, std 10.3)
- Poisson's ratio
  – Lognormal
  (mean 0.3 , std 0.015)
- Density (kg/m^3)
  – Uniform
  (Bounds [7315, 8085])
- Yielding stress (GPa)
  – Beta
  (mean 0.85, std 0.0425)

Various uncertainty models



Feng, Y., Wang, Q., Chen, X., Wu, D., & Gao, W. (2023). Virtual modelling technique for geometric-material nonlinear dynamics of structures. Structural Safety, 100, 102284.

Sana Shahoveisi

Modelling of initiation and progression of a flaw in multiphasic materials

PROJECT UPDATE
SANA SHAHOVEISI

CI – Professor Nasser Khalili	Industry – UNSW	Hub Theme 3

Project Title: Modelling of initiation and progression of a flaw in multiphasic materials

Involved:

UNSW: Sana Shahoveisi, Prof Nasser Khalili, Dr. Babak Shahbodagh

Motivation:

To Present a Framework for Modelling of Fracturing in Fluid Saturated Porous Media

Flaws and cracks resulting in failure

Benefiting from a network of artificial cracks

- Enhancing Gas/Oil recovery
- Enhancing Geothermal systems

Geothermal power project closes in SA

Knowledge gap:

- Lack a good representation of the fault's properties (opening) in Smeared methods.
- Lack a comprehensive framework with current approaches and methods.

Approach:

$\Rightarrow$ Propose a new formula and implement the methodology in a robust framework

$$\nabla \cdot \sigma' - \rho \ddot{\mathbf{u}} + \rho \mathbf{b}^* = 0,$$

$$\left[\frac{2l_0}{G_c}(1-k)\psi^{s+} + 1\right]\phi - l_0^2 \nabla^2 \phi = \frac{2l_0}{G_c}(1-k)\psi^{s+}$$

$$\dot{\mathbf{w}} = \frac{k_f}{\mu_f}\left(-\nabla p - \rho_f \ddot{\mathbf{u}} + \rho_f \mathbf{b}^*\right) \qquad w_D := h_e\, \varepsilon_{vol}$$

=> Use AI (PINNs) to provide real-time results

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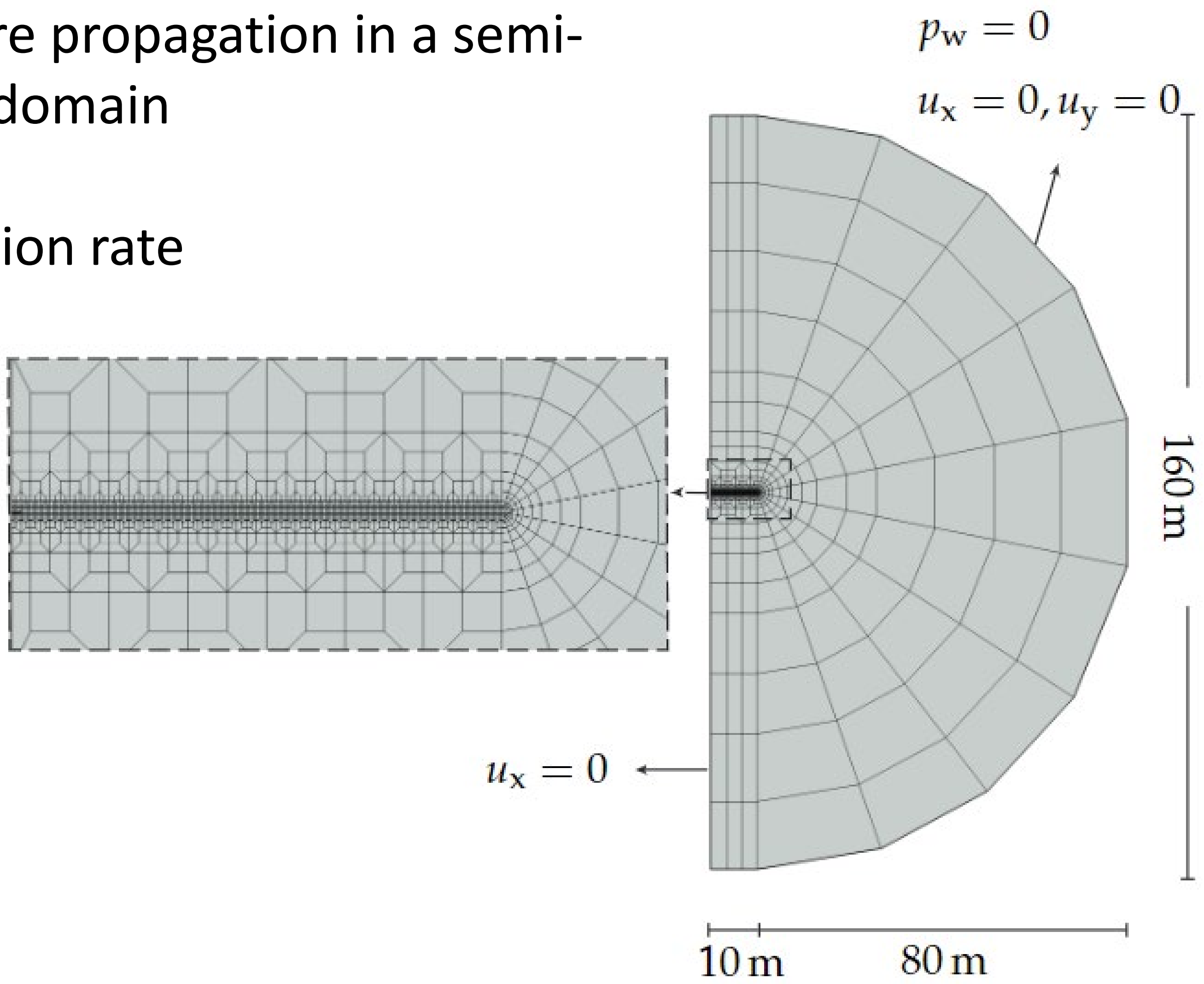
PROJECT UPDATE – SANA SHAHOVEISI

Verification example

- A fluid pressure driven fracture propagation in a semi-infinite impermeable porous domain
- Plane strain elastic domain
- Subjected to a constant injection rate

Parameters	Value	Unit
Shear Modulus	6	[GPa]
Poisson's ratio	0.2	N/A
Porosity	0.19	N/A
Bulk modulus	36	[GPa]
Flow rate	1e-4	[m^2/s]
Solid phase density	2000	[kg/m^3]



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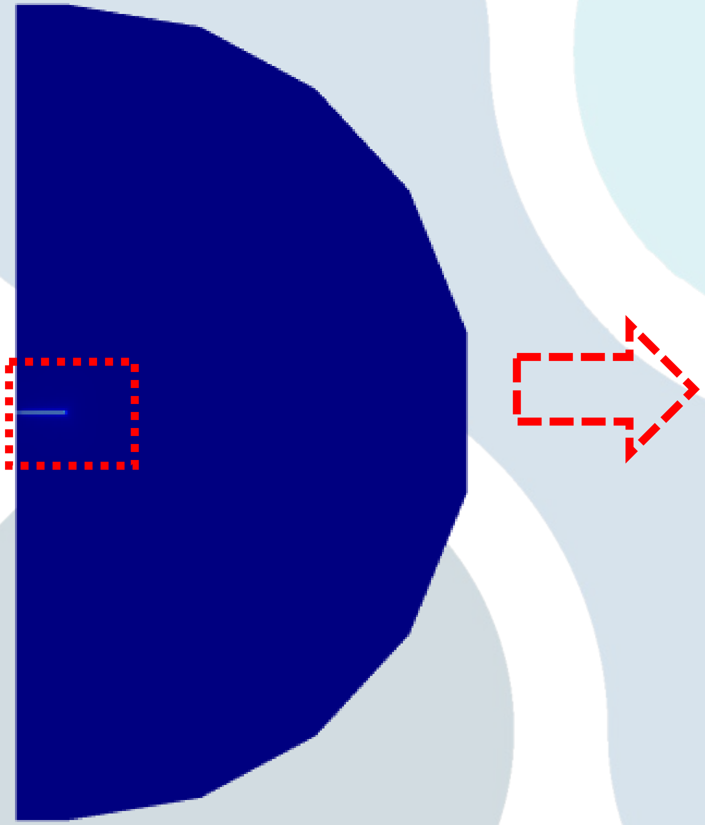
PROJECT UPDATE –
SANA SHAHOVEISI

Crack Propagation over 10 seconds



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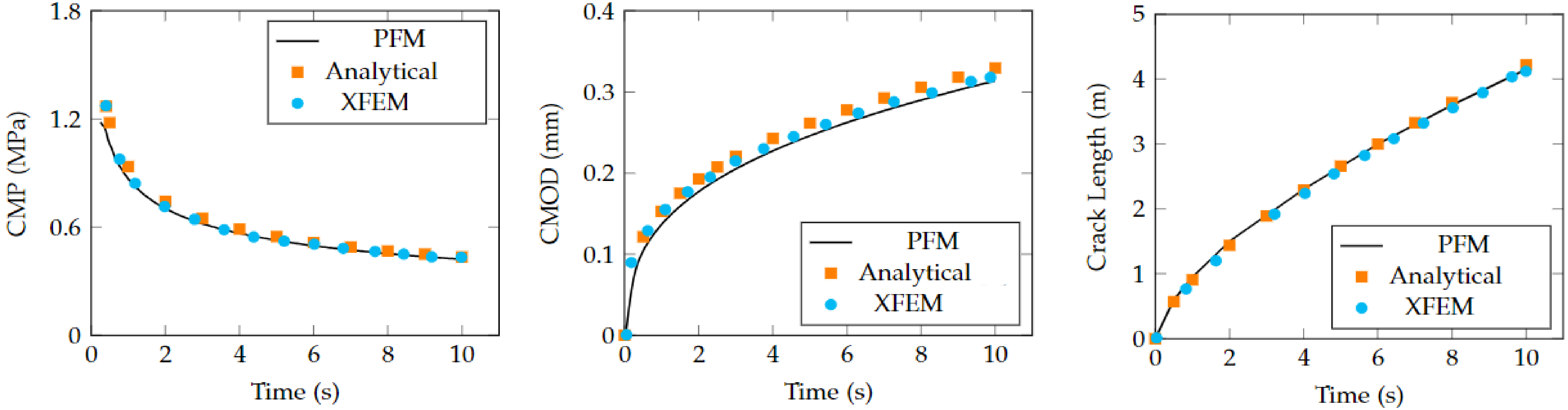
PROJECT UPDATE
SANA SHAHOVEISI

- Verifying the results with **analytical and numerical** studies

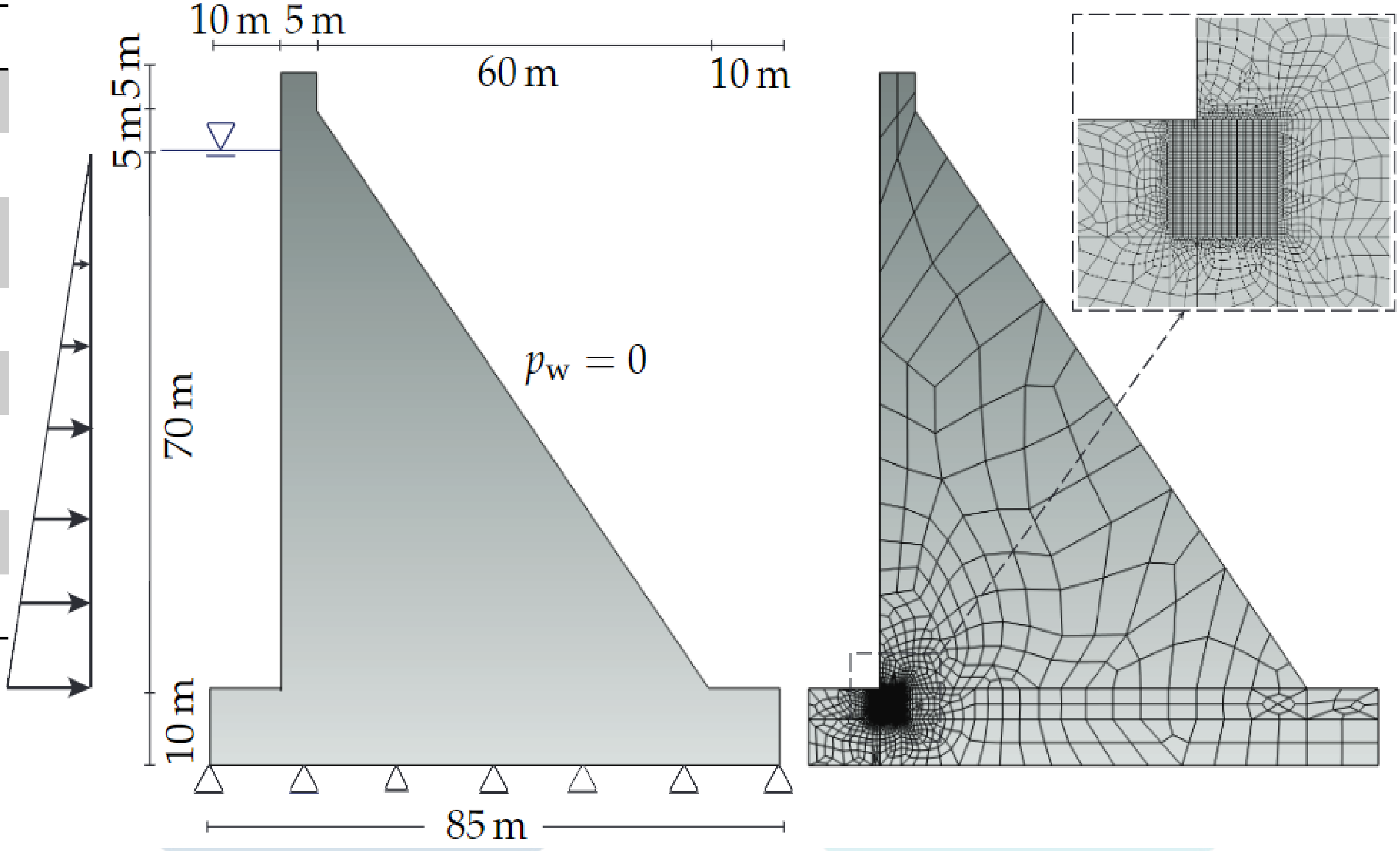


(a) (b) (c)

Gravity Dam

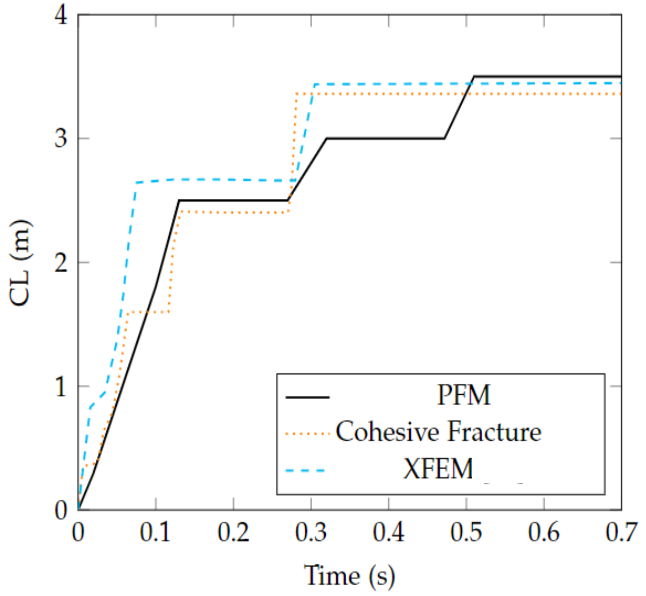
➢ Subjected to **hydrostatic pressure**

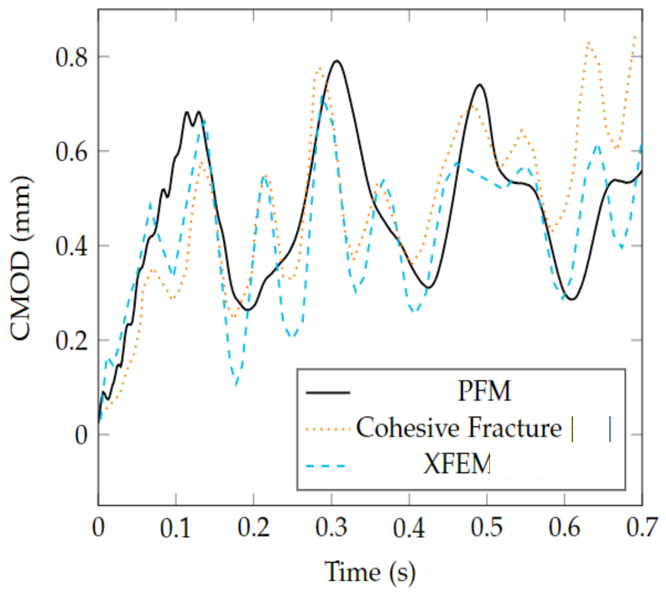
Problem parameters	Value	Unit
Poisson's ratio (ν)	0.15	
Elasticity modulus (E)	24	GPa
Solid phase density (ρ_s)	2400	Kg/m3
Porosity (n)	0.19	
Permeability (k)	1 E-12	m3/Ns
Critical energy release rate (Gc)	150	N/m
Length scale (l_0)	5	cm
Minimum mesh size	2.5	cm

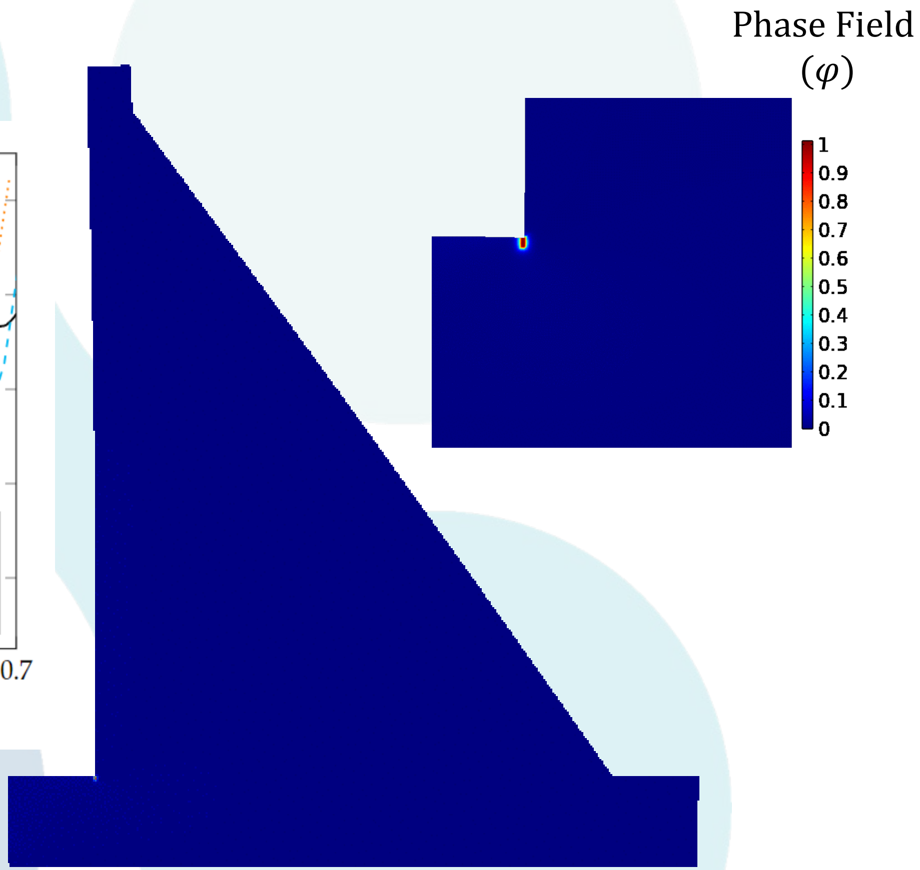


Gravity Dam

- Subjected to **hydrostatic pressure**

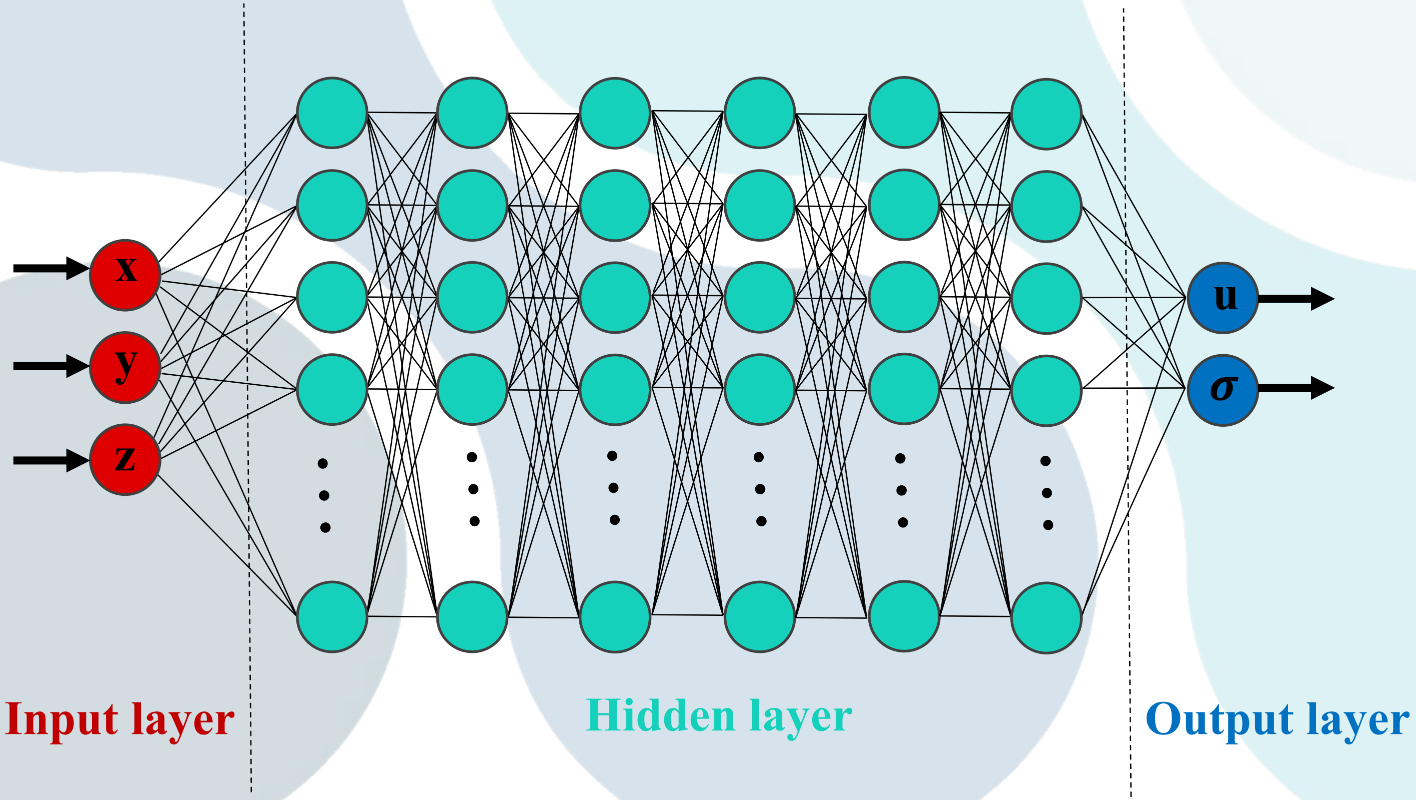






Physics Informed Neural Networks (PINNs)

- Incorporate the governing equations (PDE) in the loss function of the NN
- Training : Minimising the residual of the PDE

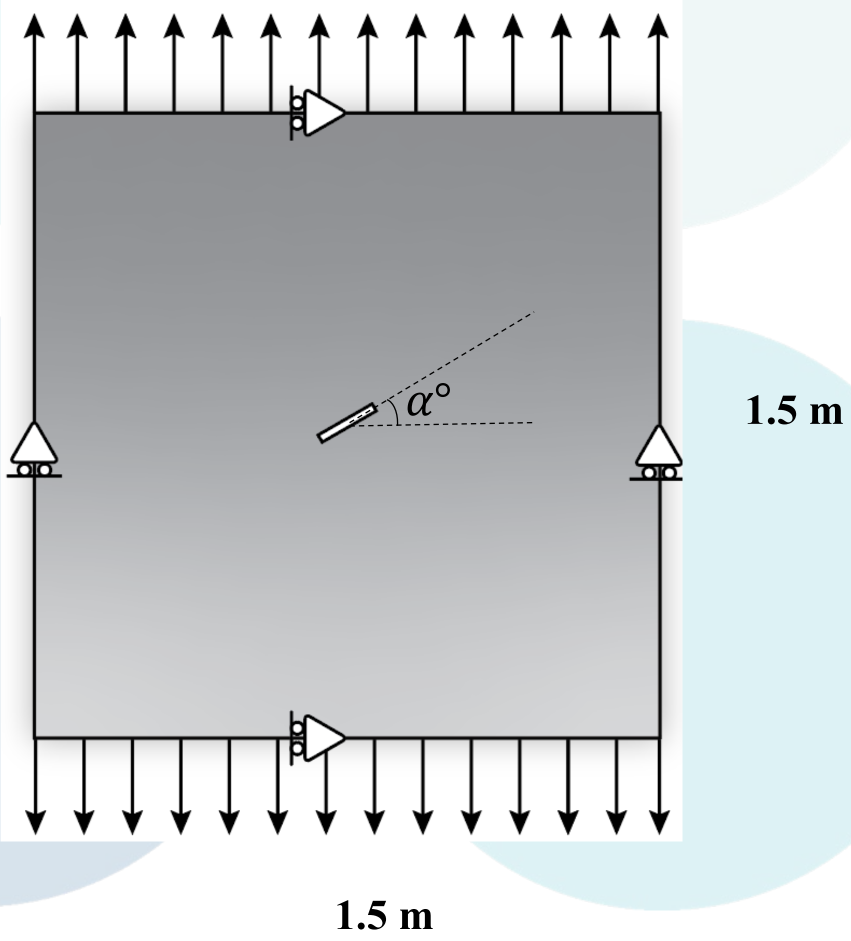


PROJECT UPDATE
SANA SHAHOVEISI

Crack Modelling

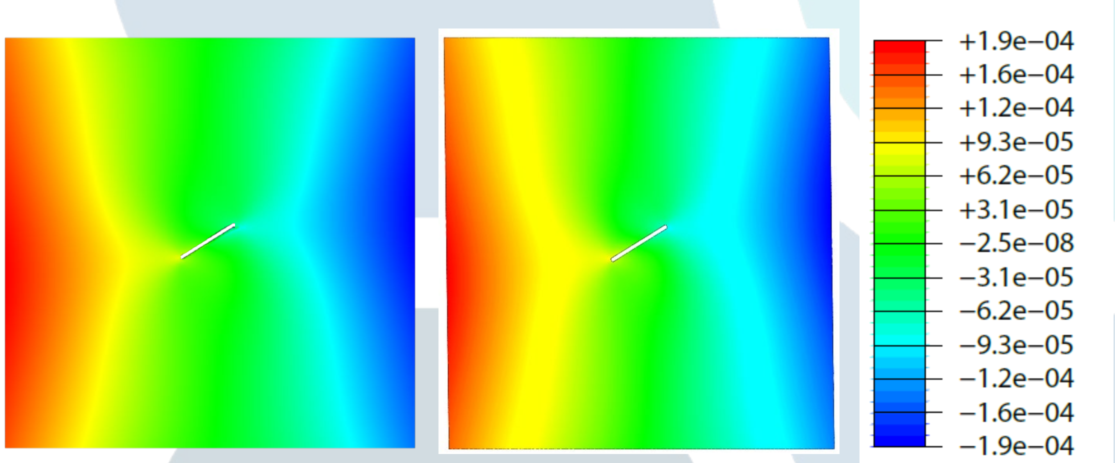
- Problem definition and boundary conditions for cracked plates
- Aluminum plate under tension
- Network 6x512

Problem parameters	Valu e	Unit
Poisson's ratio (v)	0.33	
Elasticity modulus (E)	73	GPa
Tensile load (σ_0)	50	MPa
Network number of layers	6	
Network number of Neurons	512	
a'	0.25	m
Crack width	0.015	m



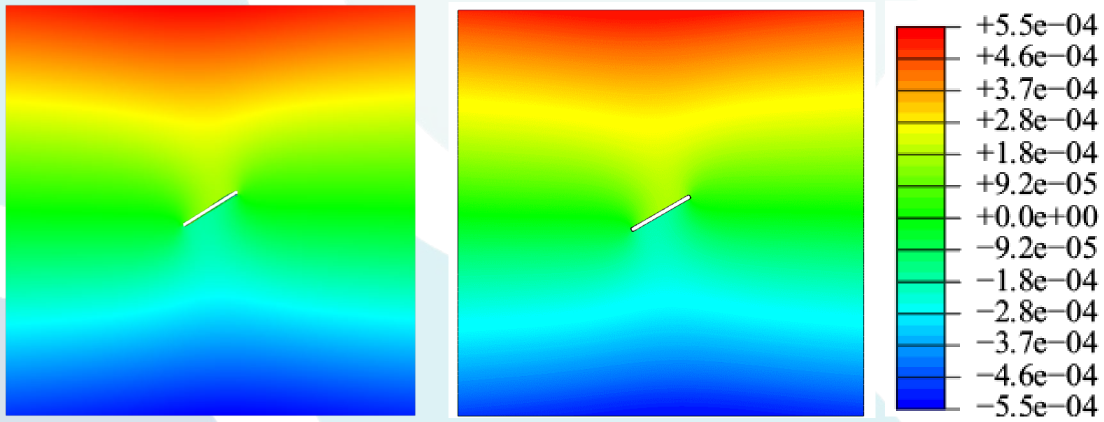
Crack Modelling

- Results for a crack inclined at 30°



(a) PINN (b) ABAQUS

Horizontal Displacement (m)

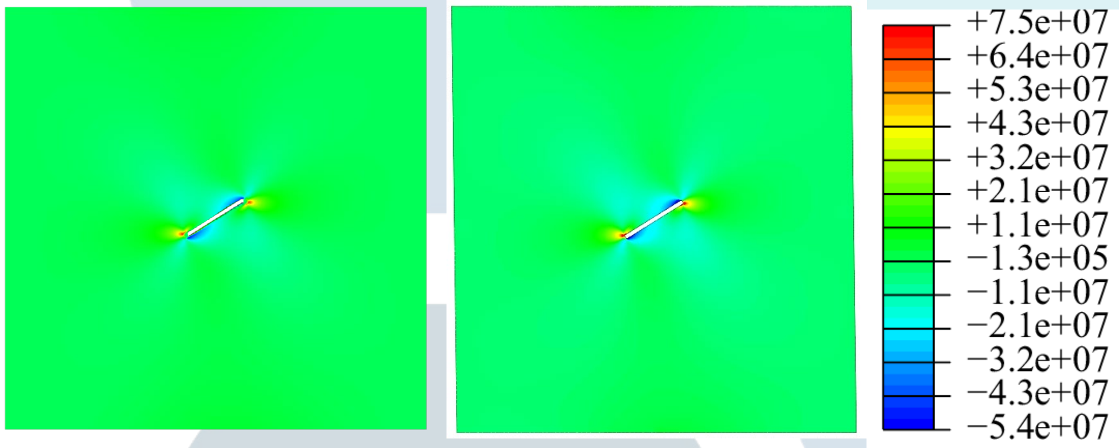


(a) PINN (b) ABAQUS

Vertical Displacement (m)

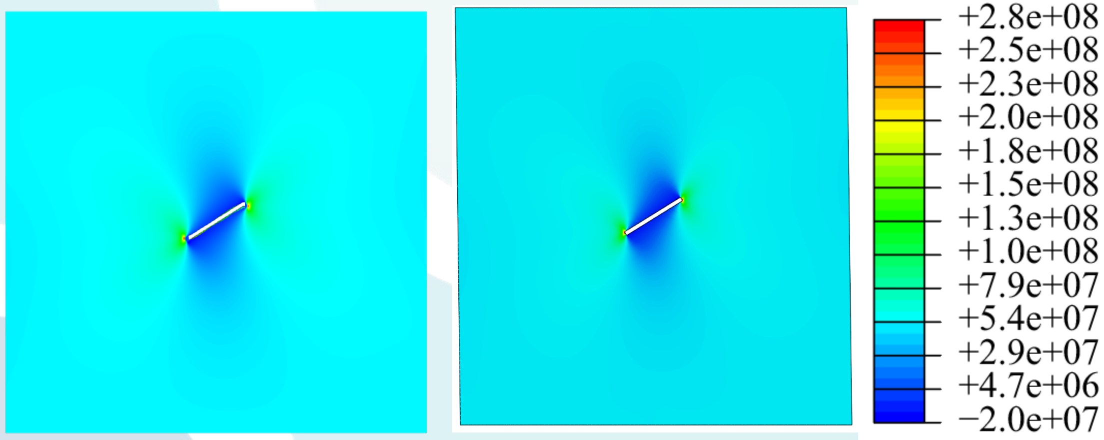
Crack Modelling

➢ Results for a crack inclined at 30°



(a) PINN (b) ABAQUS

Stress xx (Pa)



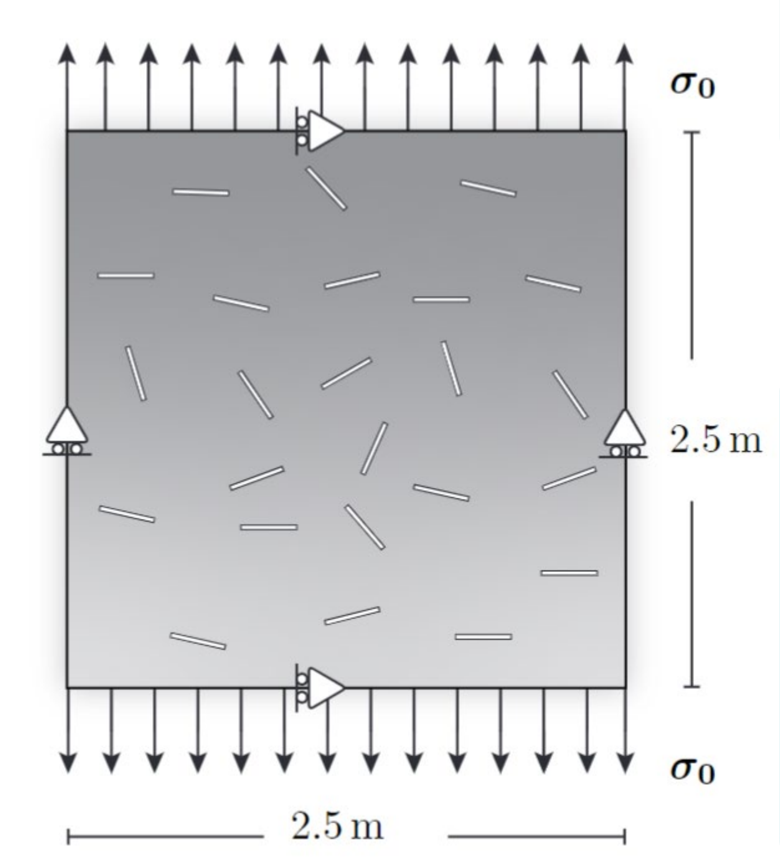
(a) PINN (b) ABAQUS

Stress yy (Pa)

Heavily Fractured Domain

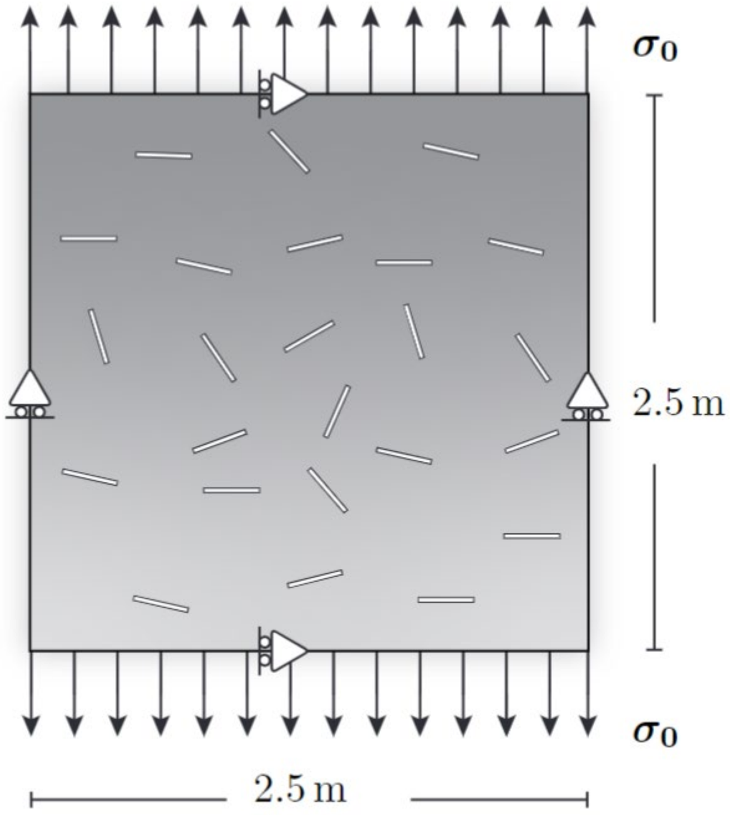
- Problem definition and boundary conditions for cracked plate

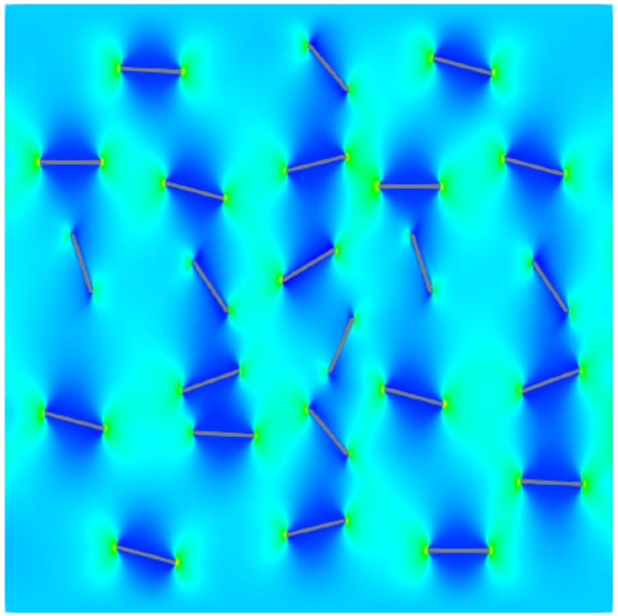
Problem parameters	Value	Unit
Poisson's ratio (ν)	0.33	
Elasticity modulus (E)	73	GPa
Tensile load (σ_0)	50	MPa
Network number of layers	6	
Network number of Neurons	512	
a'	0.25	m
Crack width	0.015	m



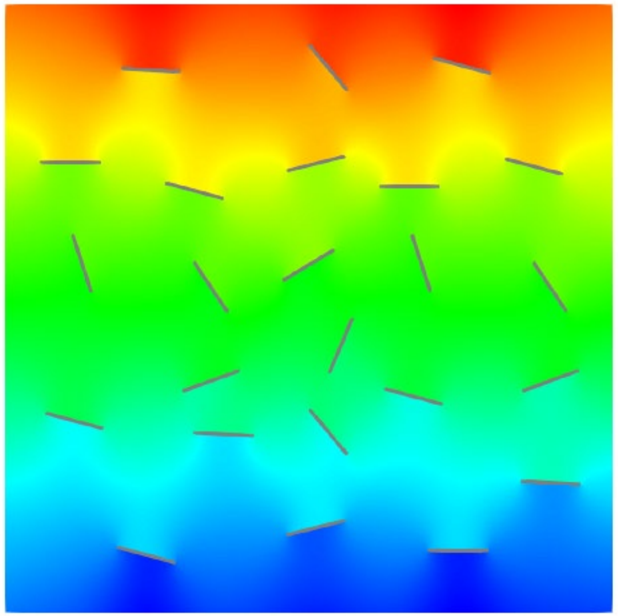
Heavily Fractured Domain

Results





Stress yy



Vertical displacement

THEME 3 PROJECT

Dr Mohsen Mousavi

Structural Integrity Assessment of Port Systems through Anomaly Detection Using Dynamic Signature Analytics and Small Strain Vibration from Wave Action

PROJECT UPDATE
MOHSEN MOUSAVI

CI –Dr Mohsen Mousavi	Industry – Ports Australia	Hub Theme 3

Project Title: Structural Integrity Assessment of Port Systems through Anomaly Detection Using Dynamic Signature Analytics and Small Strain Vibration from Wave Action

UNSW: Dr Mohsen Mousavi, Dr Ulrike Dackermann, Professor Nasser Khalili

PhD student is selected, start December 2024

Motivation:

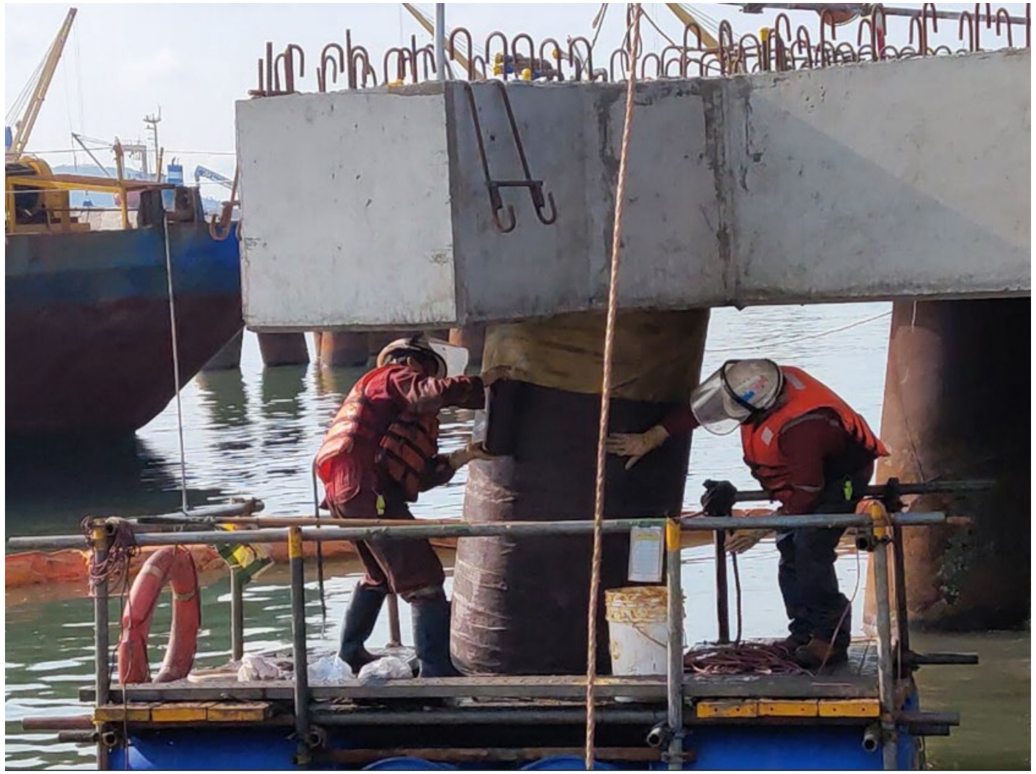
To provide a more accurate, efficient and continuous means of assessing structural integrity of port systems to improve their design and operation

PROJECT UPDATE – MOHSEN MOUSAVI

Problem statement and practical gaps

Traditional human-operated pile condition assessment

- ✓ Subjective
- ✓ Time-consuming
- ✓ Discrete
- ✓ Prone to human error



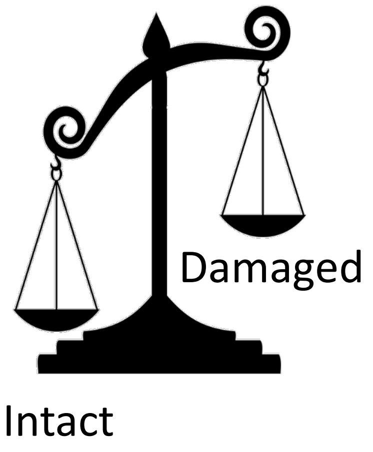
Existing Approaches & Gaps: A) Unbalanced classification

Challenges:

A1) Insufficient labelled data for the damage case

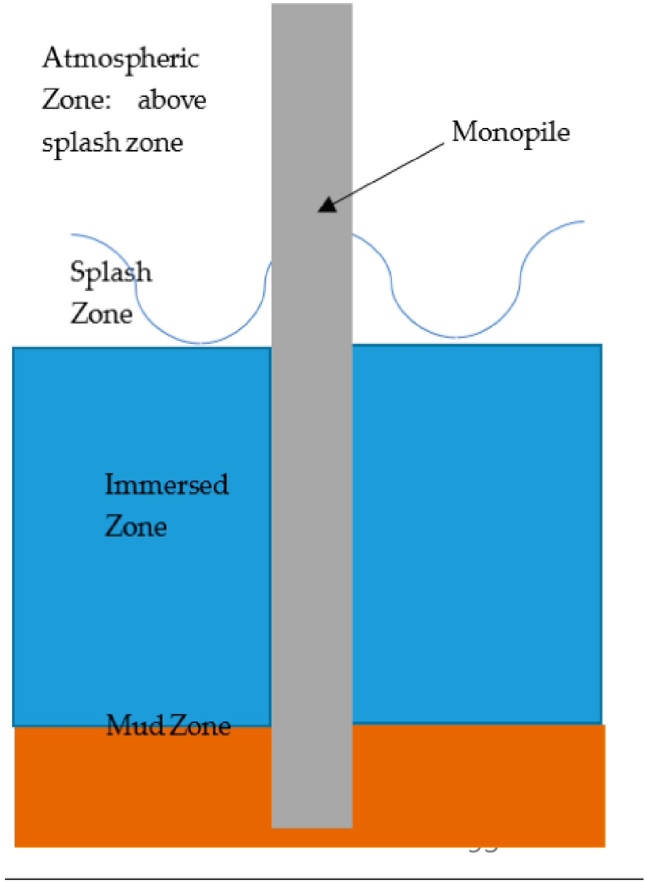
A2) Damage features are sensitive to environmental variations

A1



A2

1. Wave Action
2. Currents
3. Tidal Variations
4. Wind
5. Seabed Conditions
6. Temperature
7. Biofouling
8. Storm Surges and Extreme Events



Existing Approaches and Gaps: B) Anomaly detection

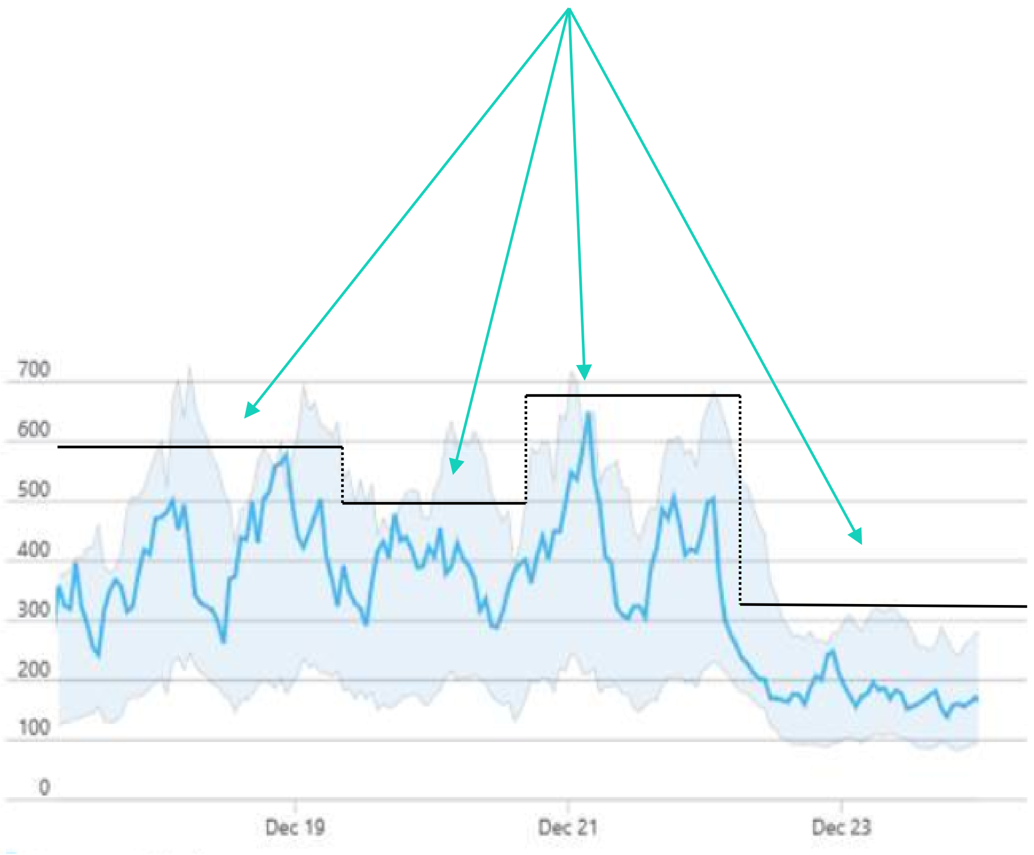
Challenges:

B1) Construct a robust damage sensitive feature (DSF)

B2) Set a robust dynamic threshold in nonstationary conditions

Dynamic threshold (B2)

DSF(B1)



Tim
e

Approach

1) Time-frequency signal decomposition
- ✓ To mitigate the effect of noise in signals
- ✓ To remove the environmental and operational effects
- ✓ To isolate long-term damage signatures

2) Obtain time-frequency statistical features (DSF)
- ✓ To develop algorithm less sensitive to environmental changes

3) Data generation using AI
- ✓ To address the data scarcity

4) Develop a predictive model
- ✓ For anomaly detection

5) Find a robust dynamic threshold
- ✓ To minimize the probability of false alarms and misses

PROJECT UPDATE

MOHSEN MOUSAVI

- ✓ Development of an adaptable framework
- ✓ Development of a user-friendly GUI

- ✓ Dissemination of project findings
- ✓ Provision of technical support

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RIIS

Professor Bijan Samali

Degradation modelling and remaining service life assessment of piers in aggressive sea-water environment

PROPOSED PROJECT

CI – Khalili/ Samali/ Chan	Industry – Kumul Petroleum	Hub Theme 4

Defined – Yet to commence

Project Title: Degradation modelling and remaining service life assessment of piers in aggressive sea-water environment.

Event presenter: Prof Bijan Samali

Industry involved: Kumul Petroleum, PNG

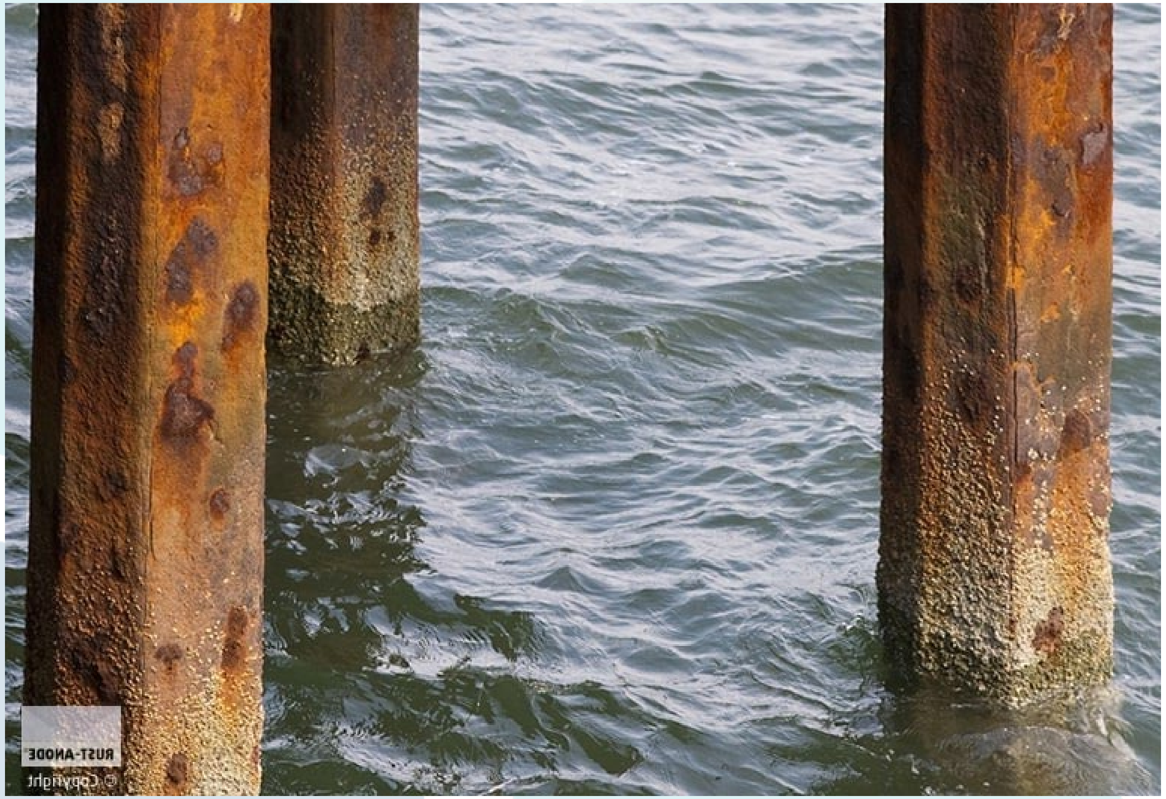
The Project scope is now defined but not yet started

Motivation:

To assist Kumul with its asset maintenance requirements and priority settings for their large stock of corroded piers.

Gap in Knowledge:

Lack of a reliable degradation model to predict the extent of pier corrosion leading to determining the remaining service life of the marine assets and the ability to estimate their remedial costs.



PROPOSED PROJECT

Aims:

- To develop an accurate and reliable corrosion degradation and progression model for steel structures in marine environments.
- To enable industry partner to make accurate predictions of remaining life of such structures and determining maintenance priorities.

Developing and testing a new model is the main objective of the project

PROPOSED PROJECT

Overview of Existing Corrosion Models

- Average Corrosion Rate Model
- Power-Law Model
- Bi-Modal Model

Limitations of Current Models

- Insufficient in addressing diverse corrosion patterns
- Lack of specific focus on specific sites
- Limited in the consideration of various parameters

The proposed research methodology

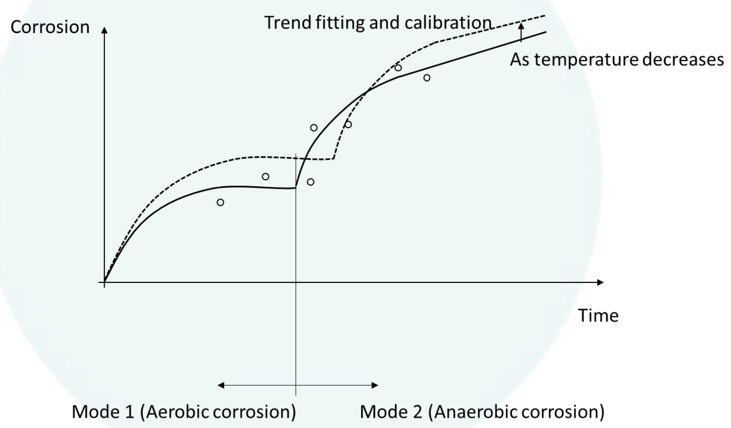
Collection of avaiable data → **Evaluating the collected data** → **Collected data are sufficient**

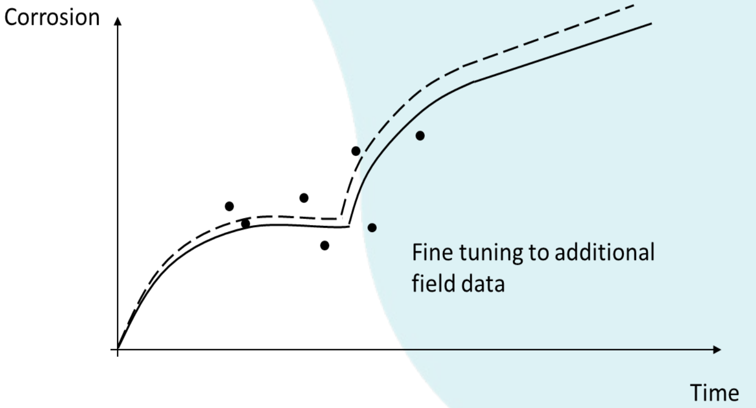
- Yes → **Data analysis and model fitting** → **Final Model**
- NO → **Conducting new measurment on some new steel plates** → Data analysis and model fitting

Depth and extent of Corrosion

Air temperature
Air salinity
Air humidity

Seawater temperature
Seawater Salinity/ Conductivity
Disolved Oxygen
Dissolved Inorganic Nitrogen





STRETCH YOUR LEGS
REST YOUR BRAIN

Short 15 Minute Break

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