SRM
INSTITUTE OF SCIENCE & TECHNOLOGY
(Deemed to be University u/s 3 of UGC Act, 1956)

الجامعة الإسلامية العالمية ماليزيا
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA
Garden of Knowledge and Virtue

Artificial Intelligence (AI) in Infrastructure Inspection

Dr. Ali Sophian, C.Eng

Mechatronics Engineering Department

International Islamic University Malaysia

1st International Conference on "Robotics in Agriculture,Bio-Waste Management and Surgery"
SRM Insitute of Science & Technology, Kattankulathur, India
14-15 September 2023

International Islamic University Malaysia

- Est. 1983
- 7 campuses in Gombak, Kuala Lumpur, Pahang & Pagoh
- Main campus is in Gombak, 10 km from the centre of Kuala Lumpur
- Around 2000 academic staff (from around 40 countries)
- More than 23k students (from more than 100 countries)

Faculties @IIUM

- LAWS
- ECONOMICS AND MANAGEMENT SCIENCES
- ISLAMIC REVEALED KNOWLEDGE AND HUMAN SCIENCES
- ARCHITECTURE AND ENVIRONMENTAL DESIGN
- ENGINEERING
- EDUCATION
- INFORMATION AND COMMUNICATION TECHNOLOGY
- MEDICINE
- DENTISTRY
- ALLIED HEALTH SCIENCES
- NURSING
- LANGUAGES AND MANAGEMENT

Kulliyyah of Engineering

- Established in 1994
- Located in Gombak campus, 10 km from the center of Kuala Lumpur
- 7 engineering departments
- 207 Academic staff and 89 non-Academic staff
- Currently caters around
  - 2200 Undergraduates
  - More than 300 Postgraduates students (PhD and MSc candidates)
- One of the largest in IIUM

Departments in the Kulliyyah of Engineering

ELECTRICAL AND COMPUTER ENGINEERING

MECHANICAL AND AEROSPACE ENGINEERING

CHEMICAL ENGINEERING AND SUSTAINABILITY

MANUFACTURING AND MATERIAL ENGINEERING

MECHATRONICS ENGINEERING

CIVIL ENGINEERING

SCIENCE IN ENGINEERING

Faculty of Engineering

Bachelor in Engineering with Honours

- Bachelor of Aerospace Engineering
- Bachelor of Chemical Engineering
- Bachelor of Civil Engineering
- Bachelor of Electrical and Electronics Engineering
- Bachelor of Manufacturing Engineering
- Bachelor of Materials Engineering
- Bachelor of Mechanical Engineering
- Bachelor of Mechatronics Engineering

Programmes Offered - MSc

- Automotive Engineering
- Biochemical Engineering
- Biotechnology Engineering
- Communication Engineering
- Computer and Information Engineering
- Chemical Engineering
- Civil Engineering
- Electronics Engineering
- Engineering Mathematics
- Engineering Science
- Manufacturing Engineering
- Material Engineering
- Mechanical Engineering
- Mechatronics Engineering

Mechatronics Engineering Department

- 30 academic staff members
- Programmes:
  - Bachelor in Mechatronics Engineering with Honours
  - MSc in Mechatronics Engineering
    - By coursework
    - By Research
  - PhD in Engineering
- 300 students approx.
- 2 intakes in a year

The Team

Academic Staff

Positions	No. of Staff
Professors	4
Associate Professors	7
Assistant Professors	19

Technical Staff

Positions	No. of Staff
Engineers	1
Senior Asst. Engineers	3
Assistant Engineers	3

- All are PhD holders (Malaysia, Australia, Bangladesh, UK, USA, the Netherlands, Japan, New Zealand)
- 5 have Malaysia's professional engineer (Ir)
- >4 have UK's professional engineer status (CEng)

Mechatronics Engineering Department

- Research Areas of the Academic Staff:
  - Robotics, autonomous systems, unmanned technologies
  - Rehabilitation robots, assistive technology, robotics for biomedical, biomechatronics, robotic hand
  - Human-robot interaction, social robotics
  - Manufacturing automation, non-conventional machining, NEMS, microfabrication
  - Artificial intelligence, Intelligent control
  - Energy harvesting, sensors, instrumentation, vibration, predictive maintenance, smart materials

Research Groups in the Department

Centre of Unmanned Technologies (CUTe)

- Unmanned surface vessel, Maritime Robotic Lab, Embedded AI Lab, Aerial Robotic Lab, Robot Design Lab, RoMocapLab (Motion Capture), MRC3 Lab (MixReality Command Control Communication), RoboMakers Lab

Autonomous Systems and Robotics Research Unit (ASRRU)

- Autonomous agent research involves many fields including robotics, machine learning, reasoning, data-mining, diagnosis, communication, real-time and control system.

Intelligent Mechatronics System Research Unit (IMSRU)

- intelligent system design, control and development, nanotechnology, mechatronics, precision engineering, signal processing, vibration control, unmanned aerial vehicles, electric vehicles, autonomous vehicles and active suspension systems.

Healthcare Engineering and Rehabilitation Research Group (HERR)

- Healthcare, rehabilitation, biosensors, biomedical instrumentation, AI and IoT, Biomechatronic

AUTONOMOUS SYSTEMS & ROBOTICS RESEARCH UNIT

IMSRU

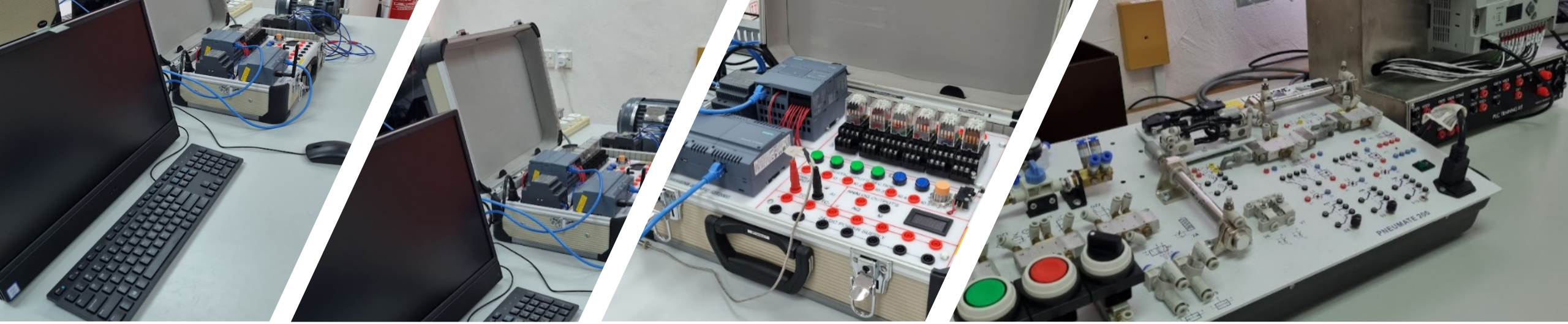
HERR
Healthcare Engineering and Rehabilitation Research Group

CENTRE FOR UNMANNED TECHNOLOGIES
CUTe

Laboratories and Workshops

No.	Laboratory Name	Area (m^2)	Student Capacity	Related Subject
1	Control Systems	153.8	30	MCT3229 : Mechatronics Engineering Lab III
2	Robotics & Industrial Automation	168	30	MCT4125 : Robotics
3	Mechatronics System Design	172.8	24	MCT4125 : Mechatronics System Design
4	Instrumentation	115.2	25	MCT3139 : Mechatronics Engineering Lab II
5	Analog Electronics	118	30	MCT3229 : Mechatronics Engineering Lab III
6	Digital Systems Design	100	30	MCT3133 : Digital Systems Design
7	Mechatronics Workshop & PCB Design	241.3	30	MCT2120 : Mechatronics Workshop
8	Machine Vision	123.6	15	MCT4323 : Machine Vision
9	Intelligent Systems	150.2	20	MCT4322 : Intelligent Systems
10	Project Development	185	15	MCT4199 : Project II
11	Industrial Automation	123.6	15	MCT4226 : Industrial Automation
12	Fluid Mechanic	242	30	MCT2219 : Mechatronics Engineering Lab I
13	Thermal Science	477.9	60	MCT2219 : Mechatronics Engineering Lab I
14	Electromechanical System	100	12	MCT3139 : Mechatronics Engineering Lab I
15	Basic Circuit	200	50	ECE1101 : Engineering Lab I
16	Electronics	232	50	ECE1201 : Engineering Lab II
17	Engineering Workshop	260	50	MME1103 : Workshop Technology

Analog Lab



Control System Lab

Mechatronics Workshop

Robotics Lab

Digital System Lab

Mechatronics System Design Lab

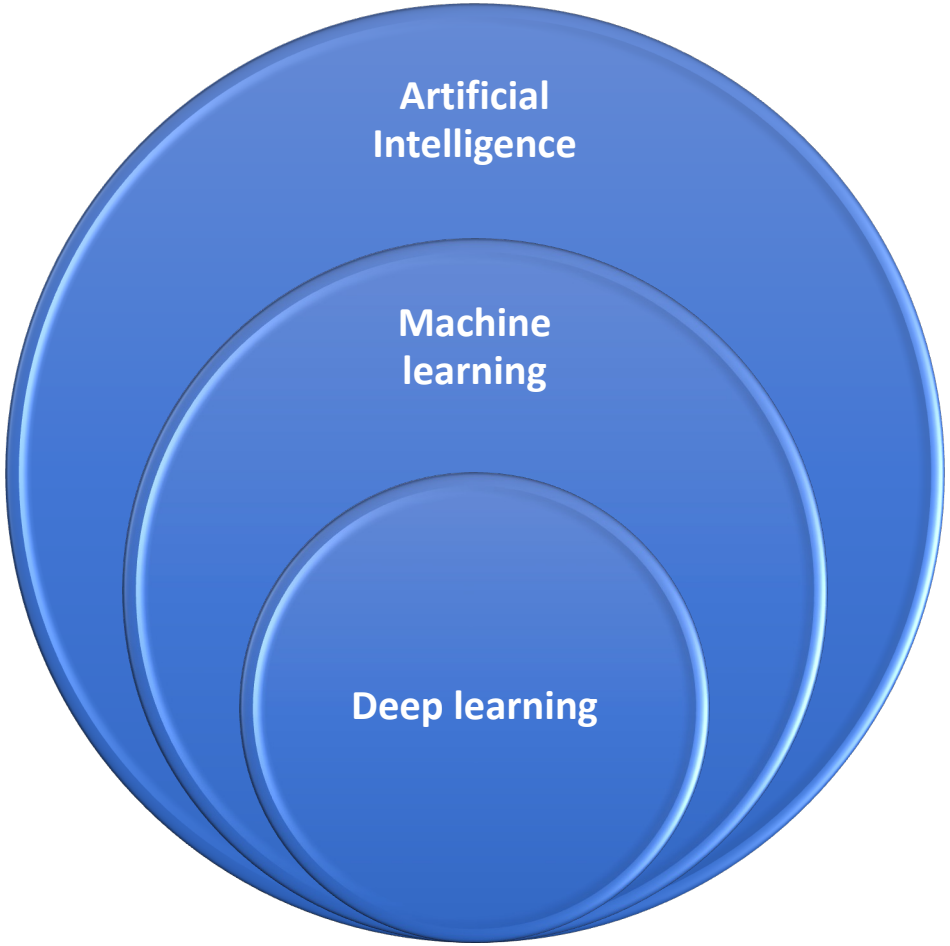
Artificial Intelligence (AI) in Infrastructure Inspection

Infrastructure - definition

- Infrastructure refers to
  - the basic systems and services that a country or organization needs in order to function properly
- It includes:
  - Transportation infrastructure
  - Energy infrastructure, such as oil and gas installations
  - Public facilities
  - Etc.

Artificial Intelligence (AI)

- AI is the ability of machines to perform tasks that are typically associated with human intelligence, such as learning and problem-solving
  - **David Poole and Alan Mackworth (2017)**: "AI is the study of how to make computers behave intelligently."
- Machine learning is a branch of AI which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy.



AI in Pulsed Eddy Current NDT for Structural Inspection

FRGS and PRGS projects – funded by Ministry of Higher Education

Collaboration with

- Malaysia Nuclear Agency
- Liverpool John Moores University, UK
- Danamin Sdn Bhd (previously)

Structural inspection

- Why is it important?
  - Ensuring the safety, functionality, and longevity of infrastructure
  - Compliance with regulations
  - Protection of valuable assets.
  - Sustainability
- Inspection employs non-destructive testing (NDT) techniques and systems

Non-destructive Testing (NDT)

- NDT techniques leverage different physical principles. The family includes:
  - Ultrasonic Testing (UT)
  - Radiography Testing (RT)
  - Magnetic Particle Testing (MT)
  - Liquid Penetrant Testing (PT)
  - Eddy Current Testing (ECT)
  - Visual Testing (VT)
  - Acoustic Emission Testing (AET)
  - Others
- The NDT techniques complement each other across various applications

- NDT is used for:
  - Measurement of material properties, such as conductivity, thickness,
  - Detection and quantification of defects, such as cracks, voids, porosity, inclusions, corrosion, and delamination

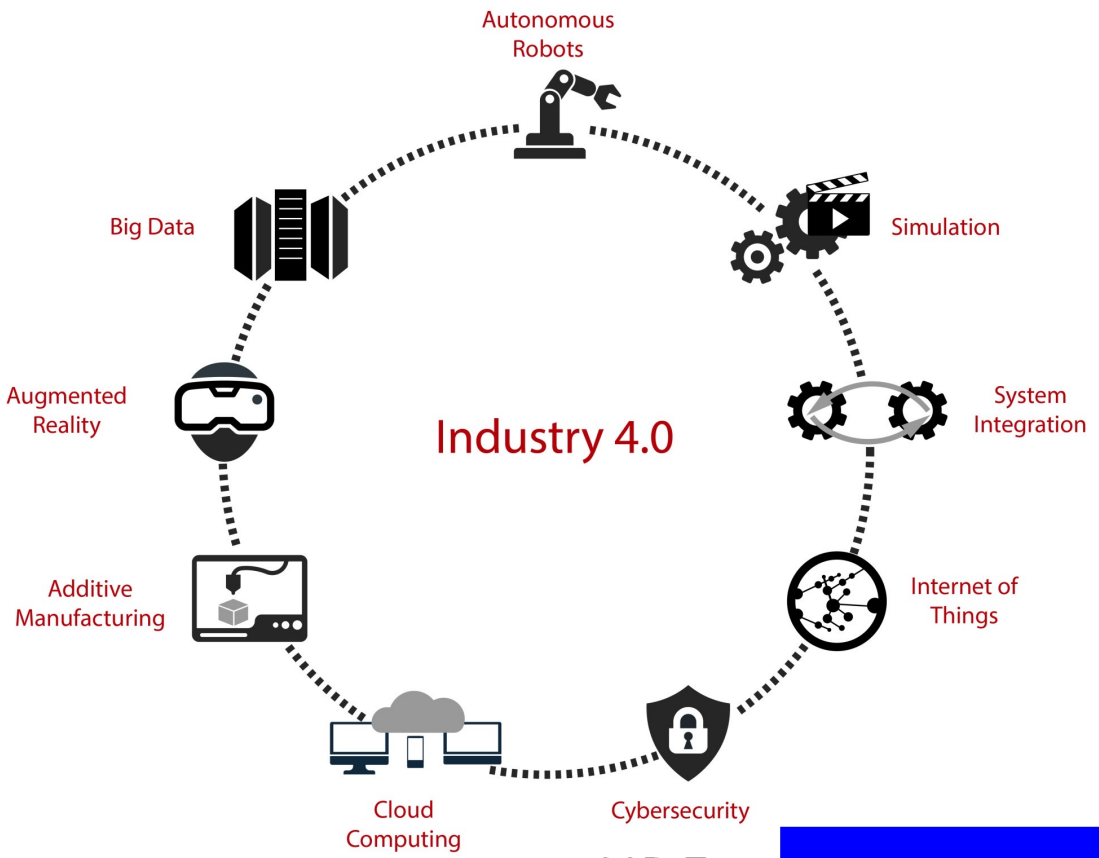
The value of the NDT business

- Global market value
  - 2021: USD 6.3 billion
  - 2029: USD 16.66 billion (predicted)

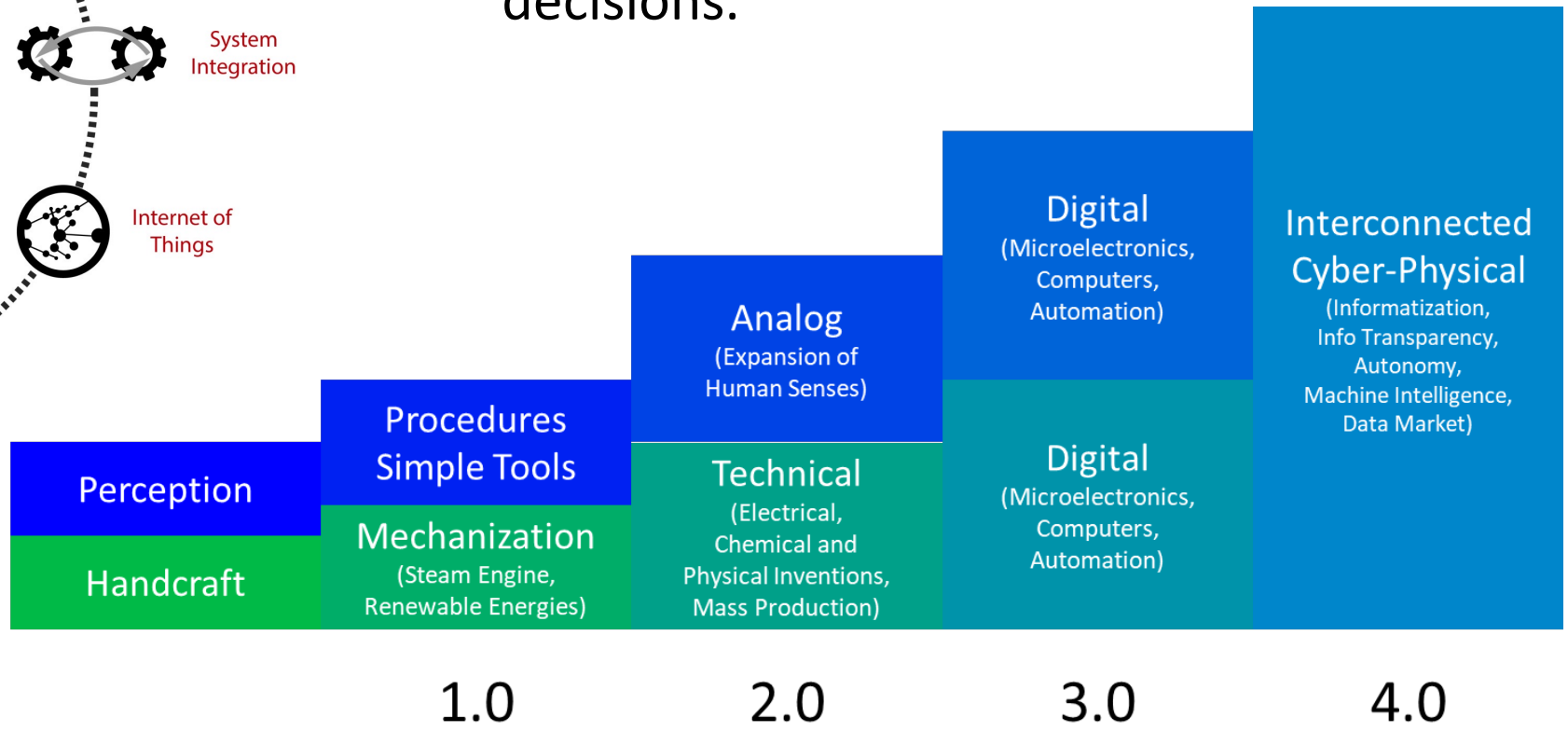
Effects of Undetected Defects

- San Bruno pipeline explosion, 2010 in US
  - Caused by defective welds on 30 inch diameter natural gas pipes.
  - 8 people were killed.
  - The company, PG&E, was fined $1.6 billion by the California Public Utilities Commission and $3 million by a federal jury for violating pipeline safety laws[4].

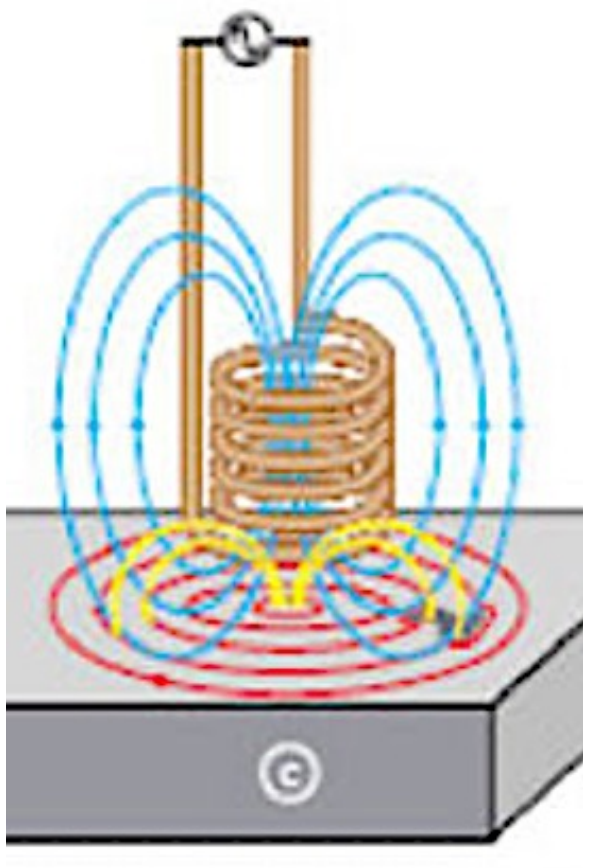
NDT 4.0



- The 4th revolution in NDE/NDT is also known as NDE 4.0 and NDT 4.0. It describes the transparency of information, technical support and autonomous and decentralized decisions.

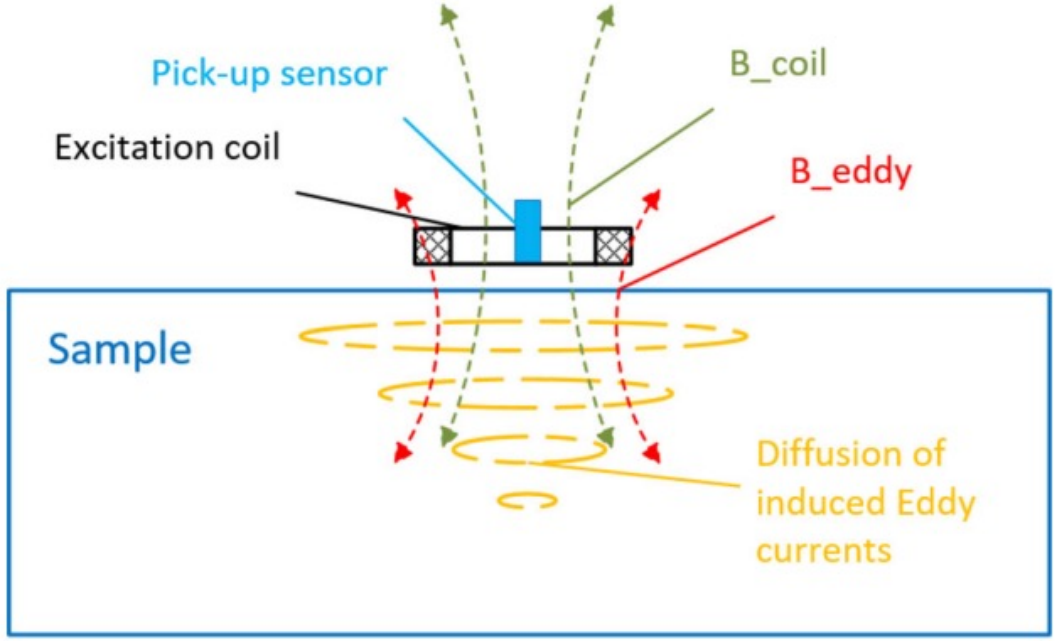


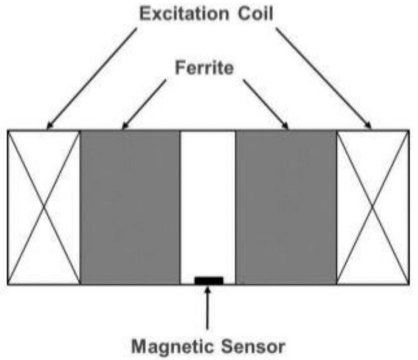
Eddy Current NDT

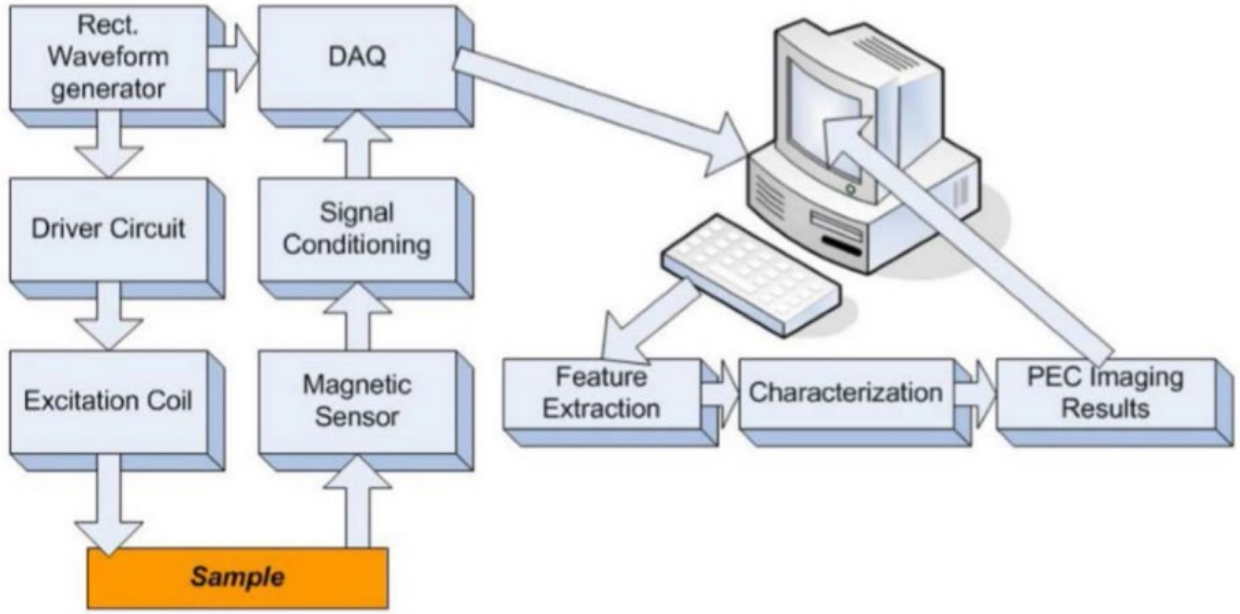


- Based on electromagnetic induction, which induces eddy currents in the structure/materials being inspected.
- Presence of defects or change of material properties affects the eddy currents.

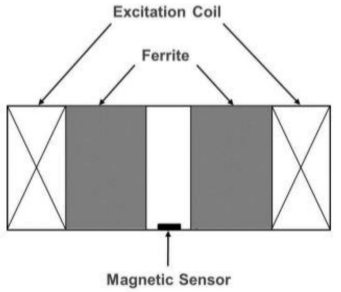
Pulsed Eddy Current NDT



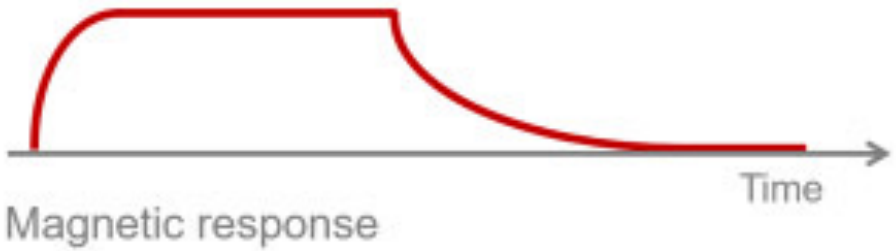




Pulsed Eddy Current (PEC) NDT

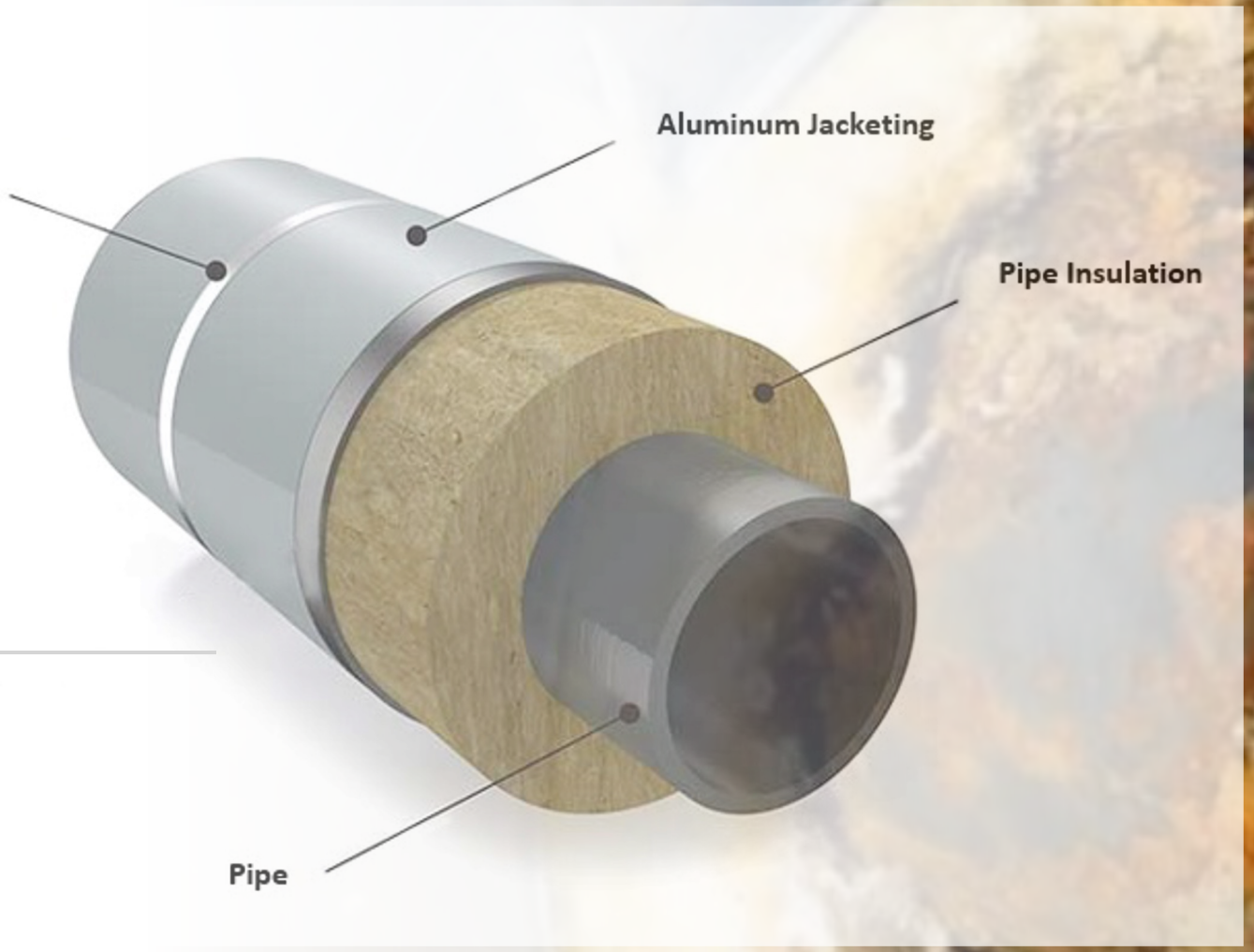


$$\frac{d\ln(V_H(t)|_{t\gg 0})}{dt} \approx -\frac{\pi^2}{\mu\sigma d^2}$$

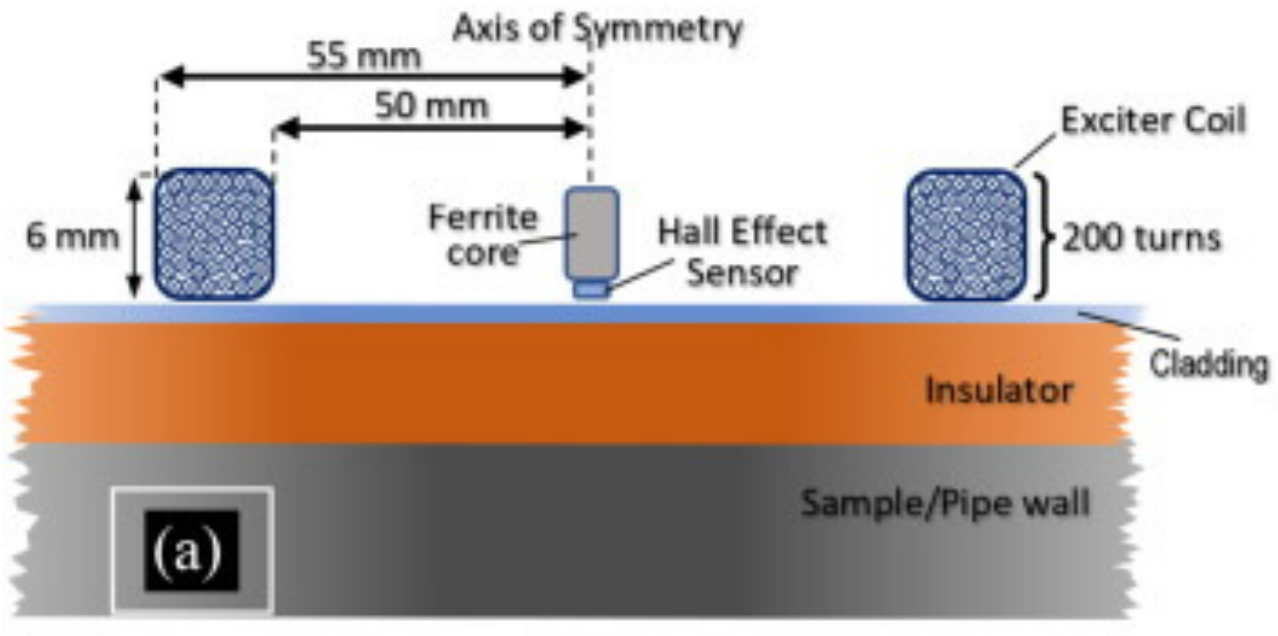


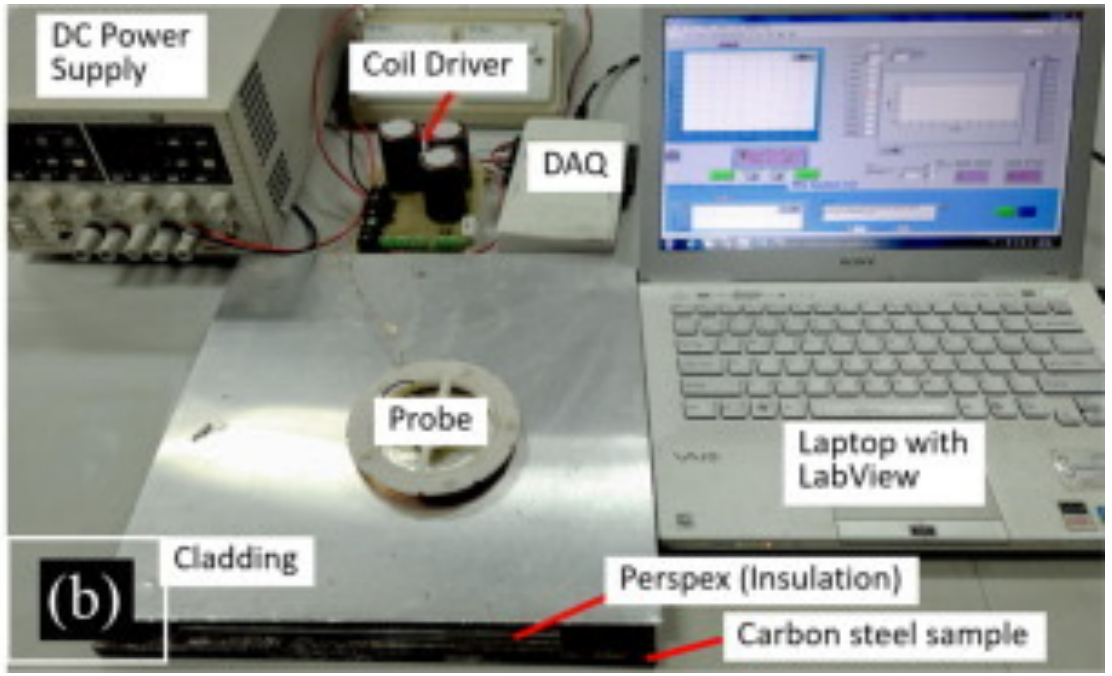
- The gradient of the decay of the signal in logarithmic space is estimated to be inversely proportional to the square of the ferromagnetic plate's thickness.

Corrosion under Insulation

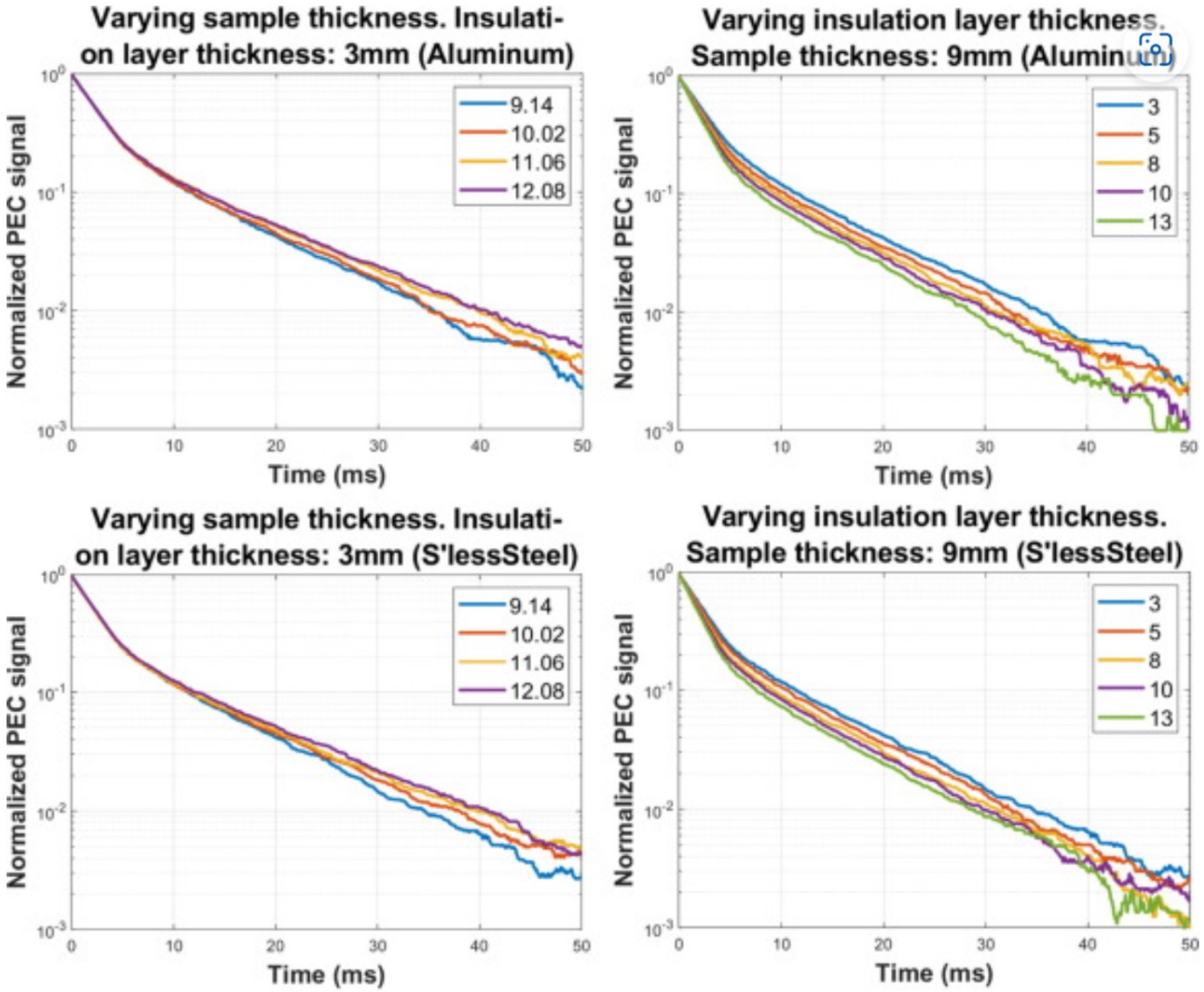


Probe Design and the Setup





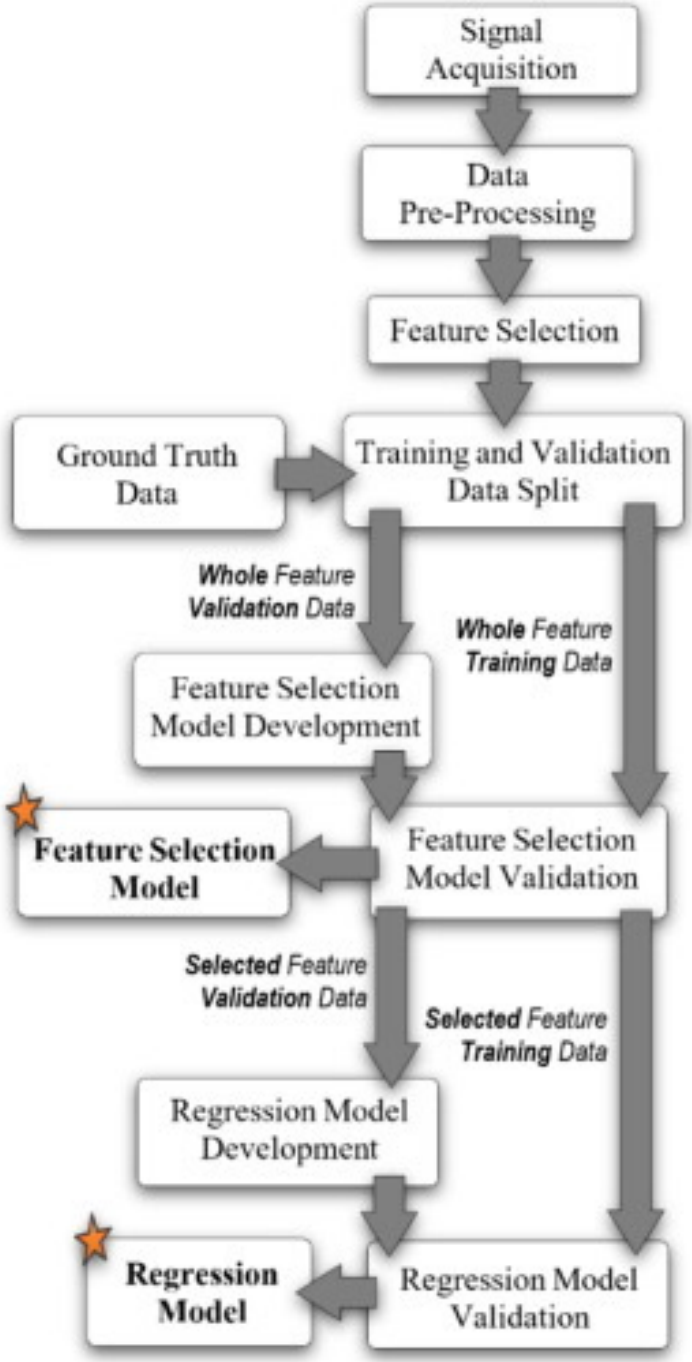
Obtained Signals – For training and validation



- Varying sample thicknesses
- Varying insulation thicknesses

Regression Model Development

- Use of machine learning
- Wavelet scattering for feature extraction
- Use of machine learning
  - Neighborhood Component Feature Selection
  - Gaussian Process Regression



Results

Model	Aluminum	Stainless Steel
	ΔmRMSE	ΔmRMSE
GPX	0.046	0.023
ITD	0.149	0.156

Faster & more accurate inspection.

AI-based Road Inspection

Fundamental Research Grant Scheme – Ministry of Higher Education

Collaboration with

- Dept. of Electrical and Computer Engineering, IIUM, Malaysia
- School of Civil Engineering, Universiti Teknologi MARA, Malaysia
- Faculty of Rail, Transport, and Logistics, Technical University of Munich Asia, Singapore

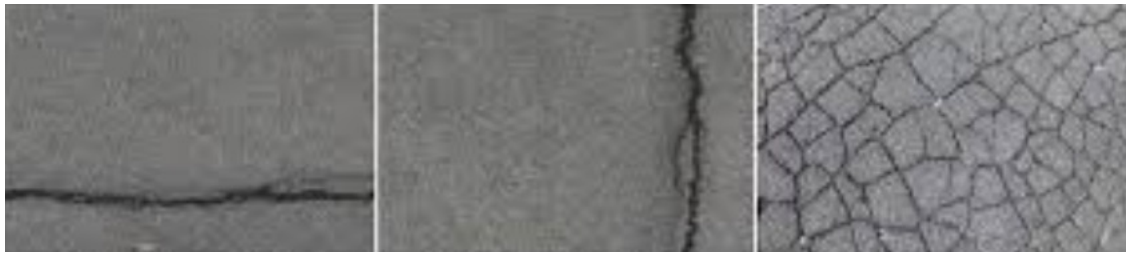
Road Infrastructure

- Roads play a fundamental role in modern society, serving as critical infrastructure with various social, economic, and environmental implications.
- The integrity and performance of pavement are very important
  - Safety, economy, environmental sustainability
- Road defects do not only degrade the road appearance and driving comfort but can also progress to cause structural damage and reduce the pavement's lifespan. They can even also lead to fatal accidents.

Common Types of Road Defects

- Potholes
- Cracks
  - Transverse
  - Longitudinal
  - Alligator
  - Etc.
- Rutting
  - formation of grooves in the wheel tracks

Detection
Classification
Characterisation



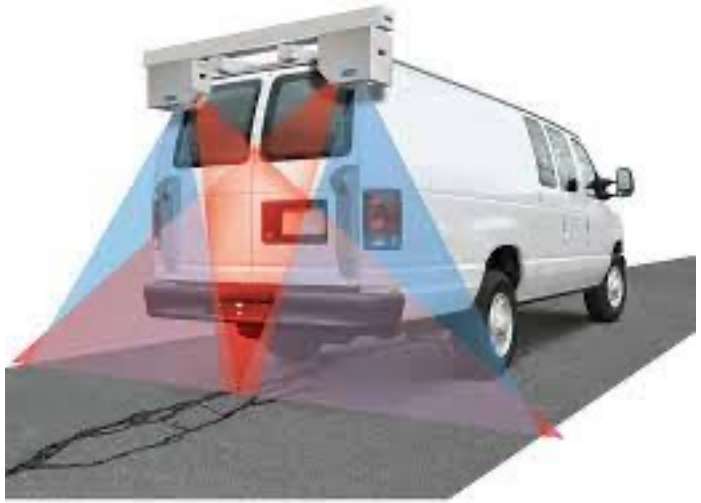
Challenges in Road Inspection

Manual

- Safety risks
- Human Subjectivity
- Costs, labor intensive
- Limited data analysis
- Inefficiency

Automated

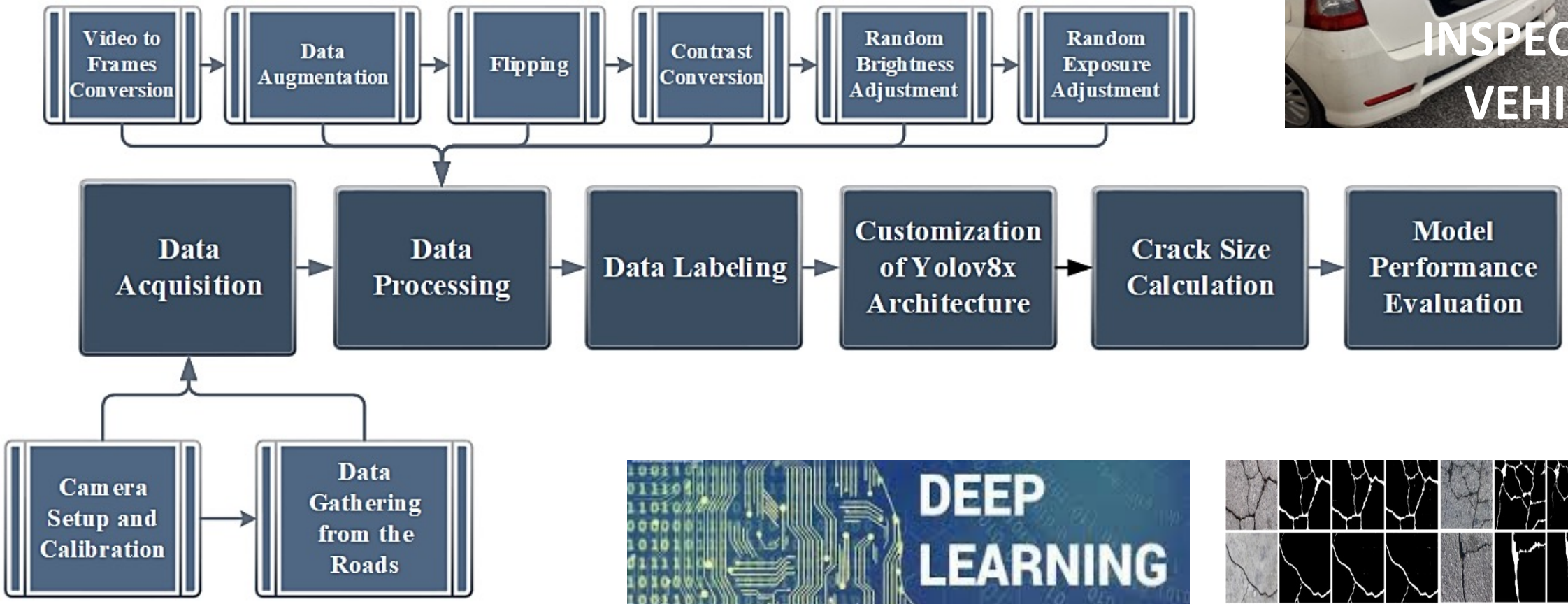
- Costly equipment

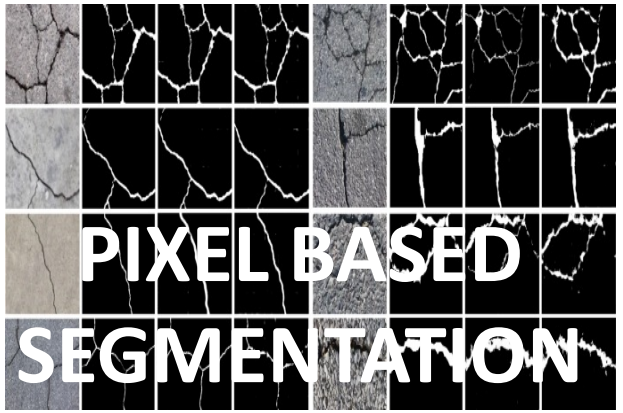


Targeted specifications

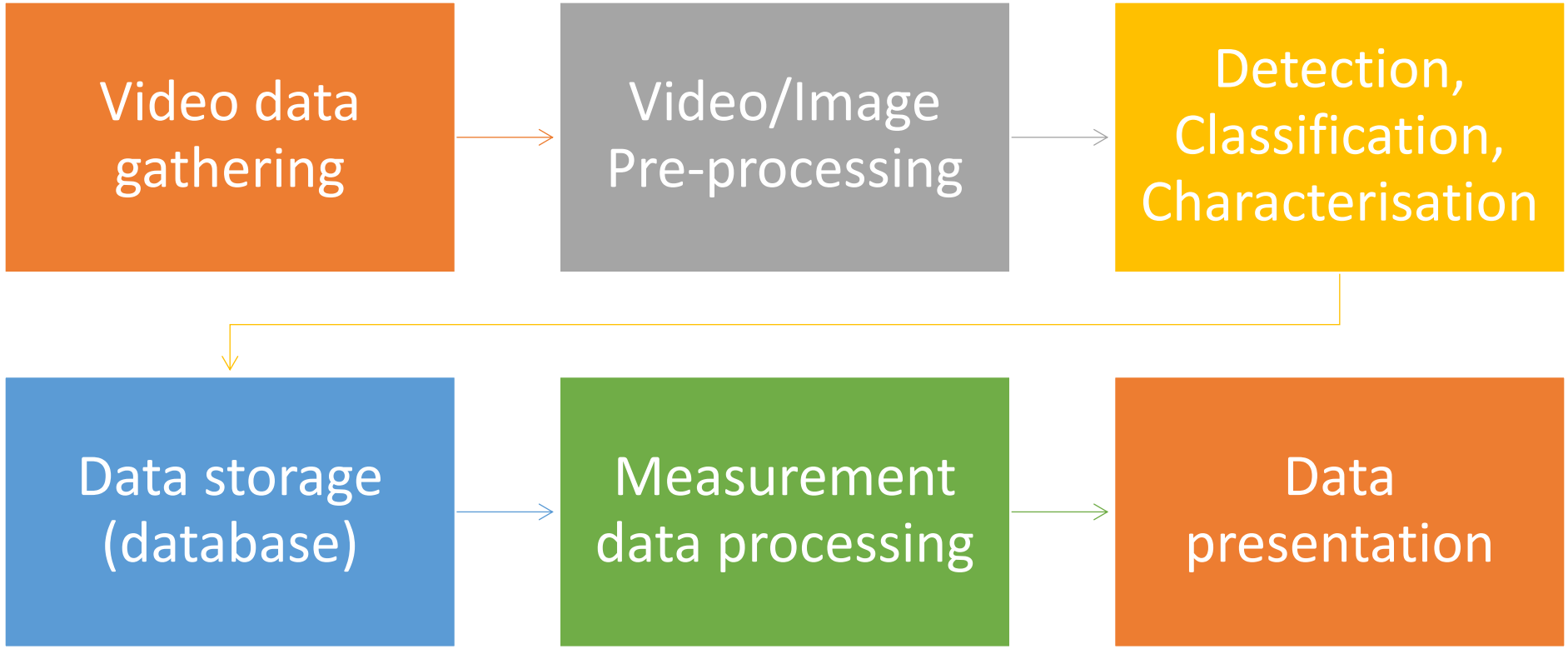
- Off-the shelf cameras
- Able to cover the whole width of one road lane
- Allow the speed of at least 30 km/h

Developed Solution (on-going)

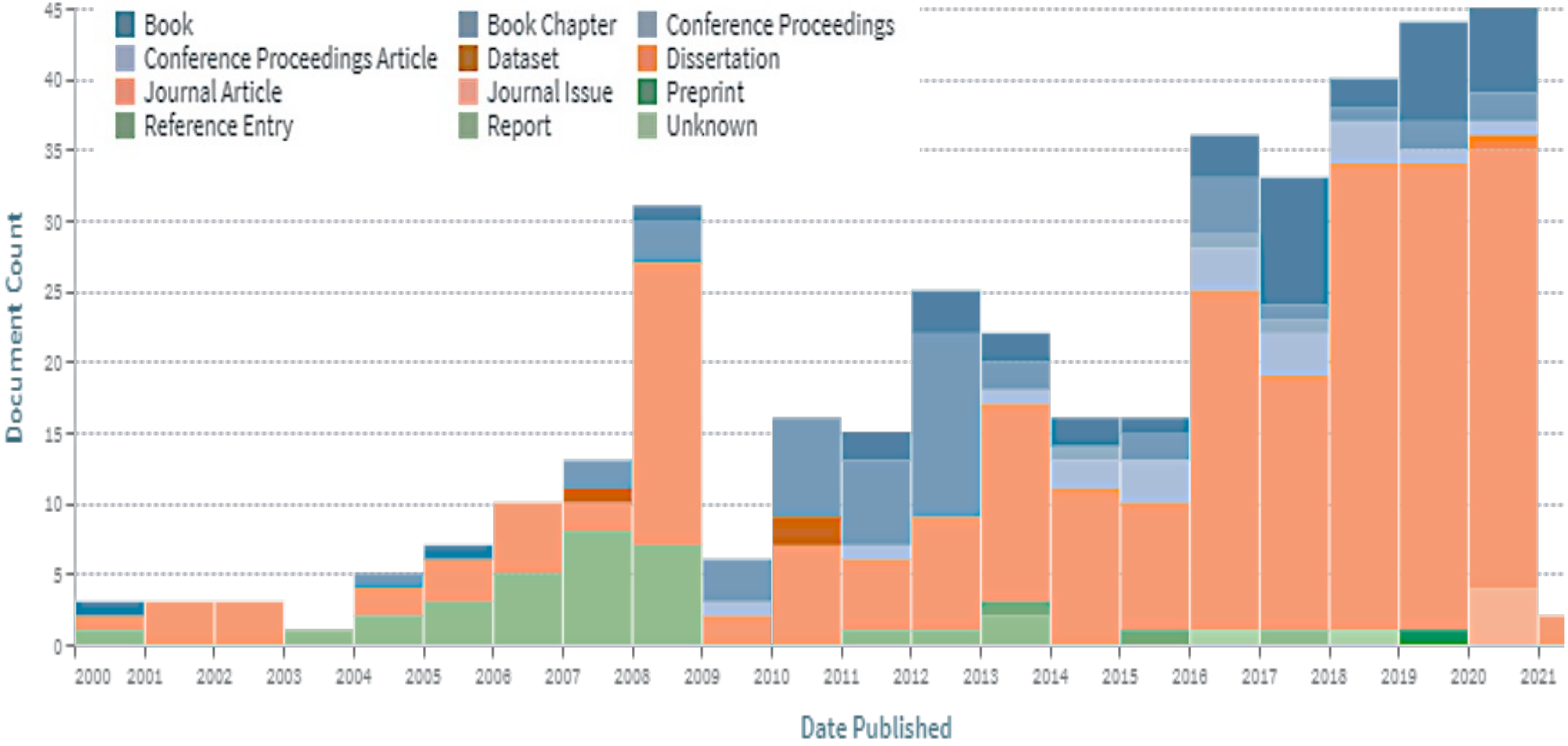


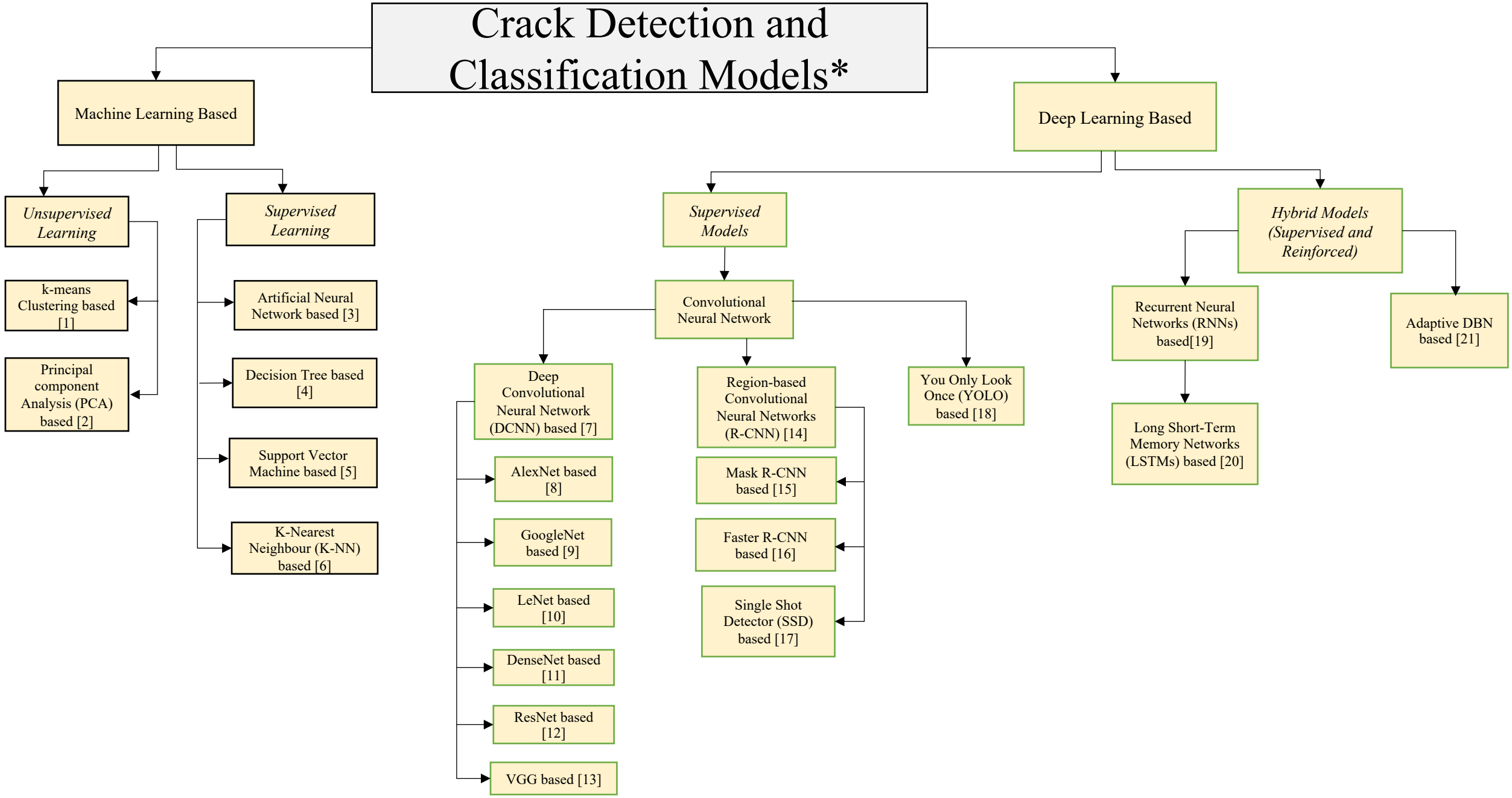


Semi-automated Integrated System



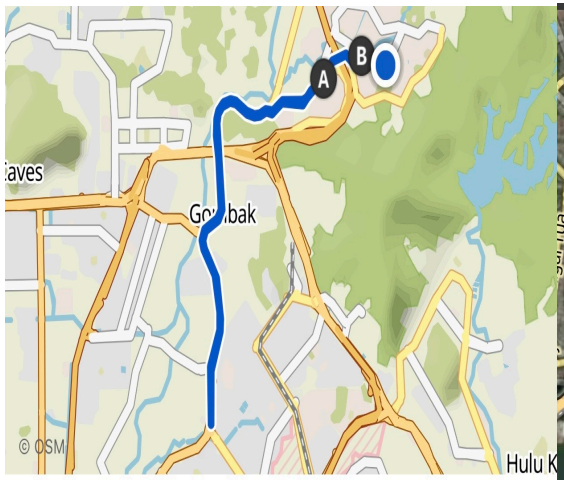
Literature on Road Crack, Classification and Characterization

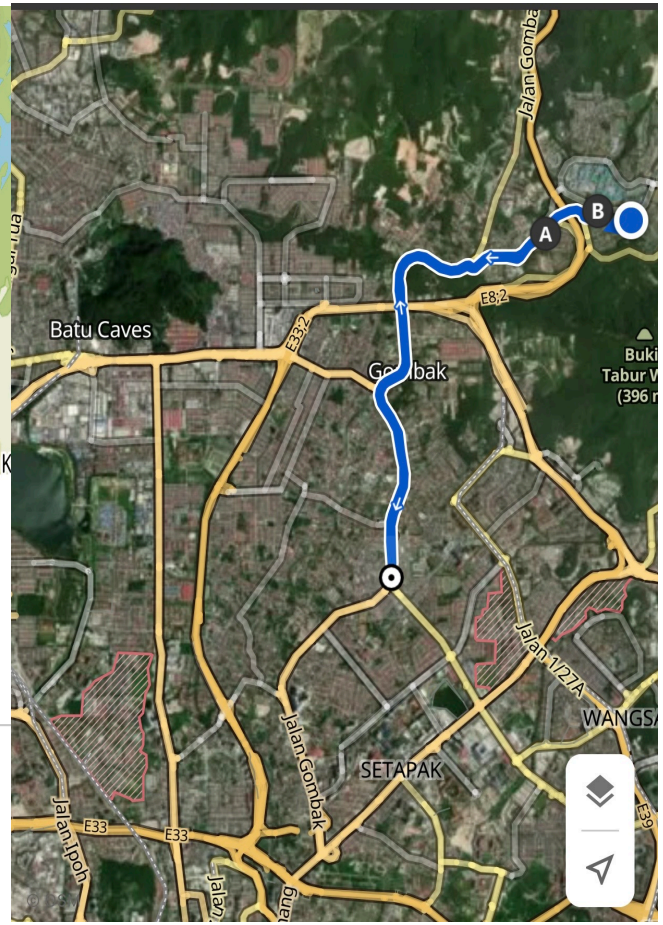



Crack Detection and Classification Models*
Machine Learning Based
Deep Learning Based
Unsupervised Learning
Supervised Learning
k-means Clustering based [1]
Principal component Analysis (PCA) based [2]
Artificial Neural Network based [3]
Decision Tree based [4]
Support Vector Machine based [5]
K-Nearest Neighbour (K-NN) based [6]
Supervised Models
Hybrid Models (Supervised and Reinforced)
Convolutional Neural Network
Deep Convolutional Neural Network (DCNN) based [7]
AlexNet based [8]
GoogleNet based [9]
LeNet based [10]
DenseNet based [11]
ResNet based [12]
VGG based [13]
Region-based Convolutional Neural Networks (R-CNN) [14]
Mask R-CNN based [15]
Faster R-CNN based [16]
Single Shot Detector (SSD) based [17]
You Only Look Once (YOLO) based [18]
Recurrent Neural Networks (RNNs) based[19]
Long Short-Term Memory Networks (LSTMs) based [20]
Adaptive DBN based [21]

Data Acquisition Setup

Data - Selangor





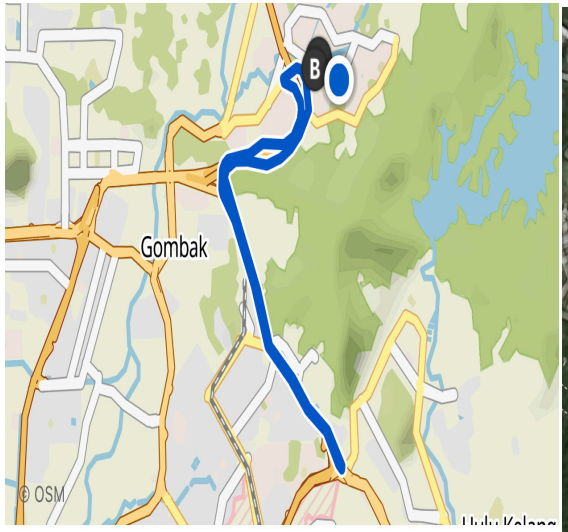
Tour

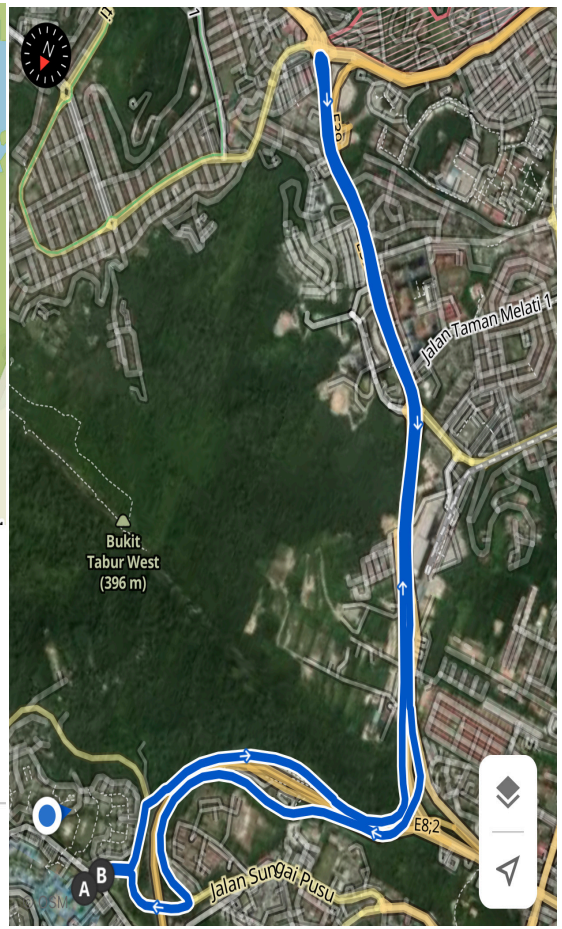
Completed on November 23, 2022

Road Ride

19 min	11.4 km	36.2 km/h	50 m

Data - KL



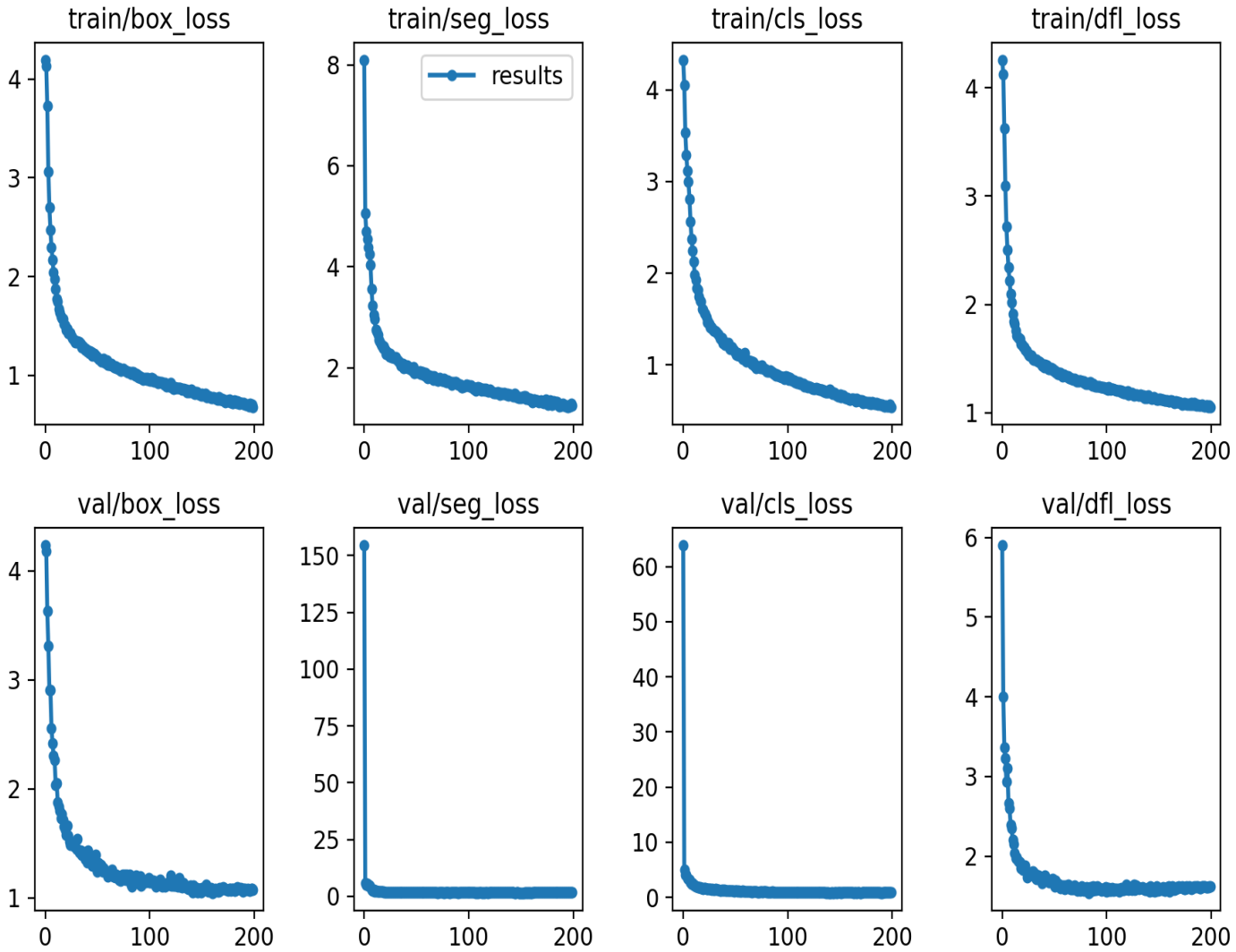


Tour

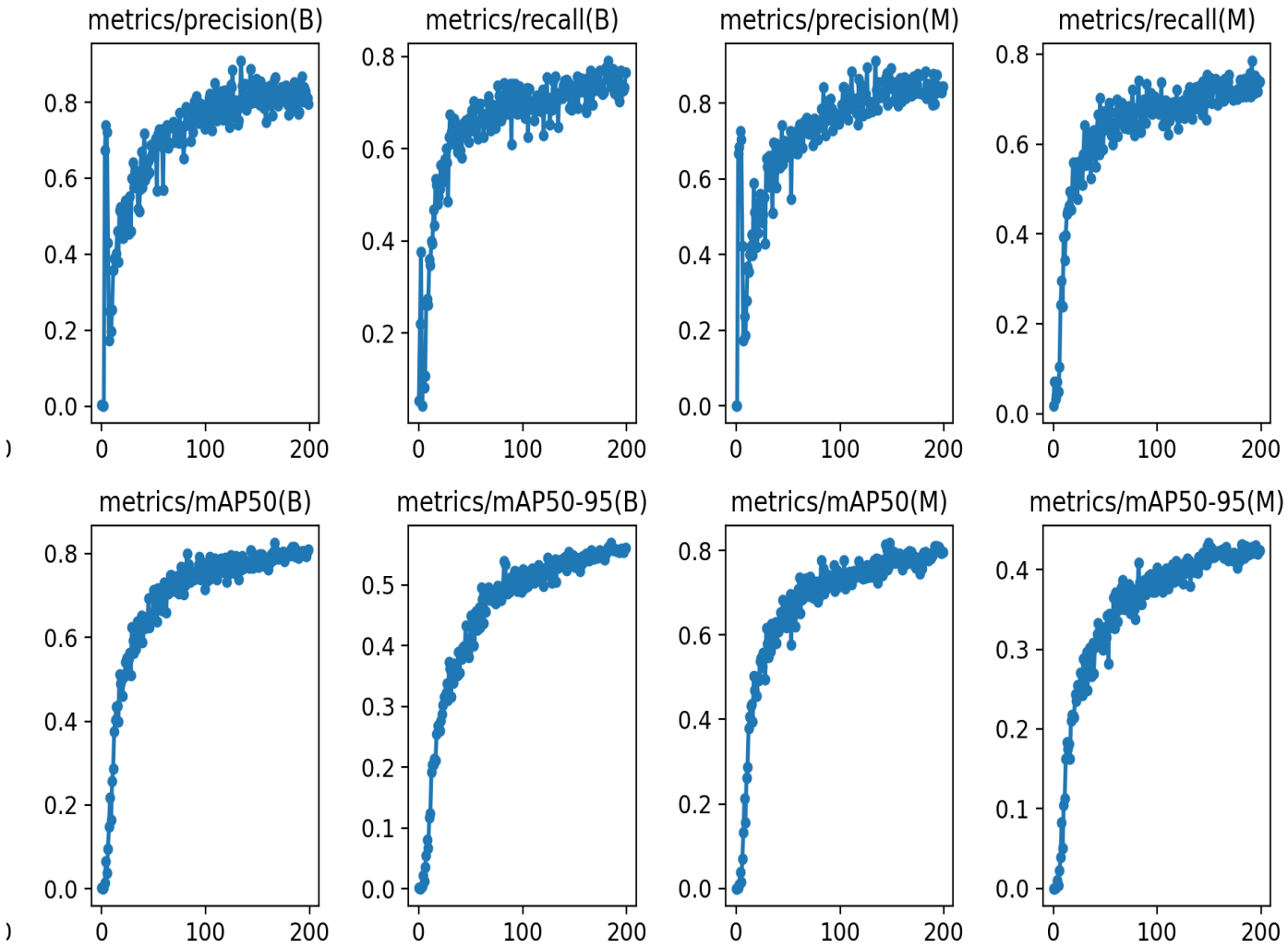
Completed on November 25, 2022

18 min	11.4 km	38.6 km/h	90 m

Training and Validation Loss Curves

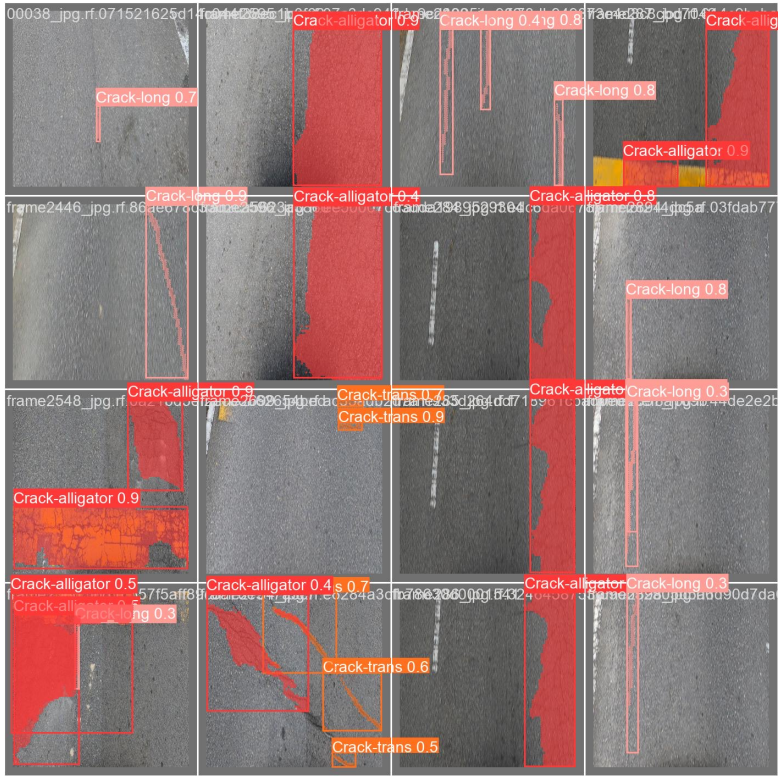


Performance Metric Curves

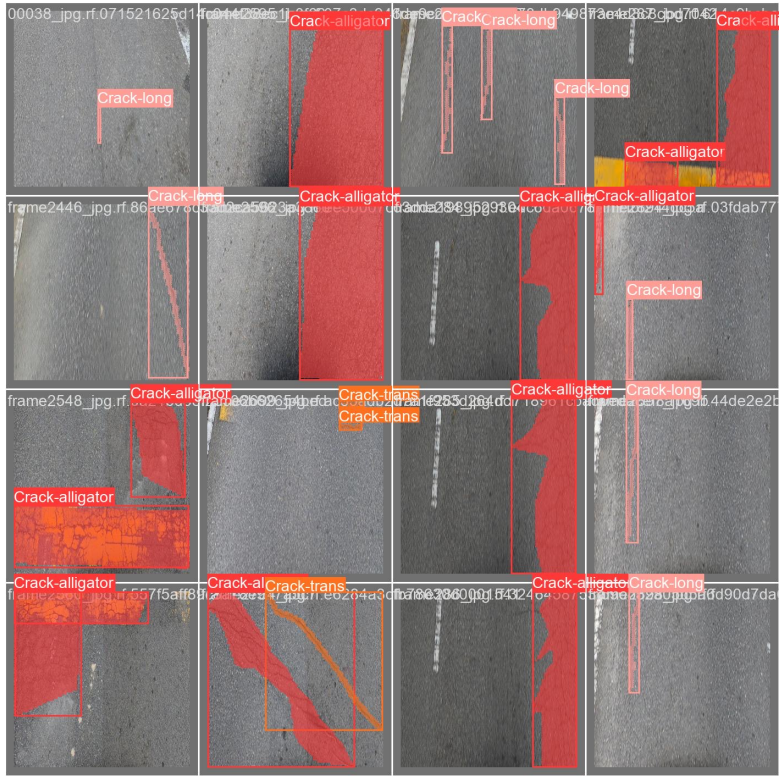


Results

Validation Set – We Annotated

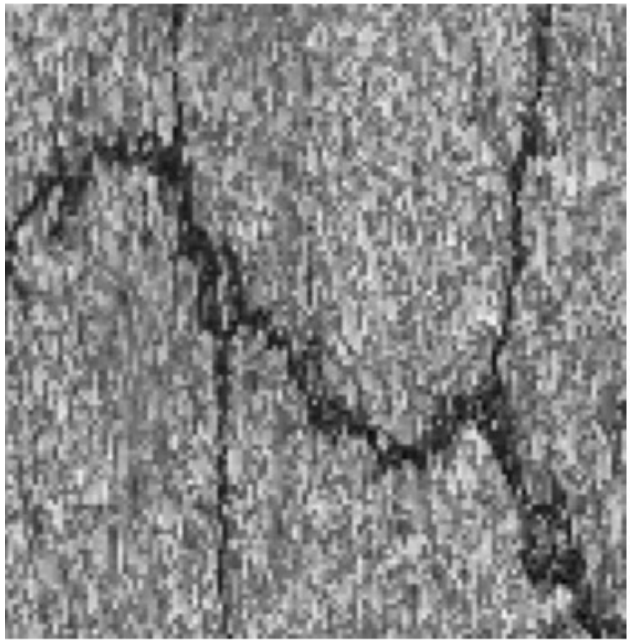


Output of the Deep Learning Model

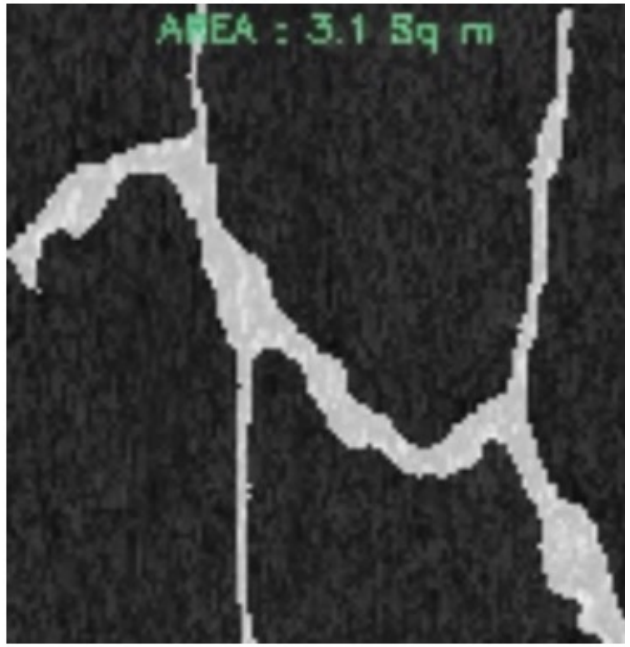


Longitude:0.6437149

Image 1



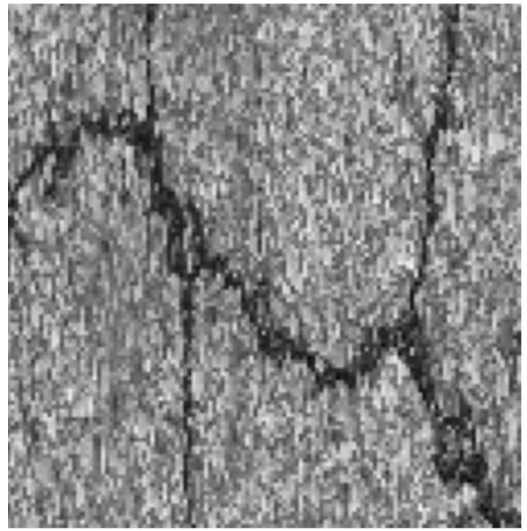
Aligator:0.8784443



Transverse:0.685978

Results

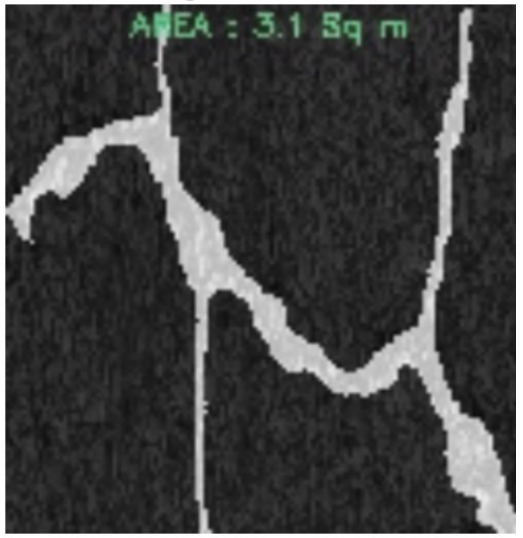
Image 1



Longitude:0.6437149

Transverse:0.685978

Aligator:0.8784443



Conclusions

- The 2 cases presented here are just a couple of examples showcasing the high potential of AI in the inspection application domain. AI offers:
  - Robustness against noise in the signal
  - Speed
  - Accuracy
  - Data integration and processing
- As we progress through IR 4.0 and NDT 4.0, the use of AI in infrastructure inspection will get more and more significant, which is instrumental for achieving improved safety, efficiency and sustainability.

Thank you.