A Research Centre admitted under AIR@InnoHK Cluster

CAiRS FOCUS II

DEC 2022

產品可靠性暨系統安全研發中心
CENTRE FOR ADVANCES IN RELIABILITY AND SAFETY

Reliability & Safety

CMRS
產品可靠性暨系統安全研發中心
CENTRE FOR ADVANCES IN RELIABILITY AND SAFETY
A Research Centre admitted under AIR@InnoHK Cluster

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

A. JAMES CLARK SCHOOL OF ENGINEERING

RESEARCH HIGHLIGHTS

MESSAGES

ABOUT CAiRS

INDUSTRY SHARING

OUR TEAM

CONTACT & SUBSCRIPTION

MESSAGE FROM THE

PolyU Vice President (Research and Innovation)

Ir Professor Christopher Chao

The Hong Kong Polytechnic University (Polyu)

""Looking ahead, I am longing for the scientific breakthroughs to be brought about by CAiRS. Our society will advance with increased momentum through the positive impacts!"

Welcome to the second issue of the CAiRS Focus magazine.

It gives me a great pleasure to welcome you to the second issue of the CAiRS Focus magazine.

This issue highlights some of the latest research work conducted by The Centre for Advances in Reliability and Safety (CAiRS) and the impacts across a wide range of industries. Since its inauguration, CAiRS has successfully attracted top researchers from all over the world to join hands in pursuit of its vision. Utilizing the most advanced equipment, research team members leverage innovative artificial intelligence technology in their product reliability and system safety research projects to accurately predict and, hence, prevent the occurrence of failures. Over 20 well-known local companies have signed cooperative research agreements with CAiRS aiming to improve reliability and safety of products and systems, laying a solid foundation for the future development of the Centre.

CAiRS was jointly established by The Hong Kong Polytechnic University (PolyU) and the University of Maryland (UMD), College Park, Maryland, USA. Destined to be a world-leading and regional hub for cutting-edge research in reliability and safety innovation, CAiRS upholds PolyU's motto of "To learn and to apply, for the benefit of mankind". With CAiRS as one of the research centres admitted under InnoHK, a flagship I&T initiative of the HKSAR Government, PolyU is proud of its contribution to driving the competitiveness of industries through innovation and technology development to sustain the long-term growth and prosperity of Hong Kong.

MESSAGE FROM THE

Director of Center for Advanced Life Cycle Engineering (CALCE)

Professor Michael G. Pecht
University of Maryland

"As part of the CAiRS team, CALCE is contributing its expertise in fundamental research in physics of failure and data-driven reliability and safety innovation."

Welcome to the second issue of the CAiRS magazine.

With the support of industry, the Hong Kong SAR Government and academia, the Centre for Advances in Reliability and Safety (CAiRS) is now putting into practice their research and development concepts. The underlying objective is to enable advanced design, manufacture and test of next generation reliable and safe electronics for transportation, consumer products, telecommunication systems, public utilities, and infrastructure in Hong Kong. In addition, we are educating the industry and future engineers. For example, the Center for Advanced Life Cycle Engineering (CALCE) at the University of Maryland has already given 28 lectures on reliability and safety science.

In CAiRS, some of the specific tasks include the use of the internet of things, syndromic surveillance, innovative diagnostics for system health management, prognostics for remaining useful life assessment, and functional safety assurance. PolyU has brought their strong experience in electronics, electrical, computer, mechanical, healthcare, transportation and industrial engineering to bear. With extensive local industrial support based in Hong Kong (e.g., HKEIA and HKEIC of FHKI), together, we have now started creating a new paradigm for reliability science and promoting customized product health management.

Prof Michael Pecht (30,000+ citations, 80+ H-Index) has a BS in Physics, an MS in Electrical Engineering and an MS and PhD in Engineering Mechanics from the University of Wisconsin. He is a Professional Engineer, an IEEE Fellow, an ASME Fellow, an ASM Fellow, and an SAE Fellow. He served as editor-in-chief of IEEE Access for six years, as editor-in-chief of IEEE Transactions on Reliability for nine years, editor-in-chief of Microelectronics Reliability for sixteen years, and editor of Circuit World. He has also served on three U.S. National Academy of Science studies, two US Congressional investigations in automotive safety, and as an expert to the U.S. FDA. He is the Director of CALCE (Center for Advanced Life Cycle Engineering) at the University of Maryland (UMd), which is funded by over 150 of the world's leading companies. He is also a Professor in Applied Mathematics at UMd. He has written more than thirty books on product reliability, development, use and supply chain management. He has also written a series of books of the electronics industry in China, Korea, Japan and India. He has written over 700 technical articles and has 11 patents. In 2015 he was awarded the IEEE Components, Packaging, and Manufacturing Award for visionary leadership in the development of physics-of-failure-based and prognostics-based approaches to electronics reliability. He was also awarded the Chinese Academy of Sciences President's International Fellowship. In 2010, he received the IEEE Exceptional Technical Achievement Award for his innovations in the area of prognostics and systems health management. In 2008, he was awarded the highest reliability honor, the IEEE Reliability Society's Lifetime Achievement Award.

MESSAGE FROM THE

Centre Director & Executive Director

Ir Professor Winco K.C. Yung

Centre for Advances in Reliability and Safety (CAiRS)

Welcome to the second issue of the CAiRS magazine, CAiRS Focus II. The second issue highlights some of our research projects and updates our promotional events.

CAiRS is the world leading and regional hub for research in Reliability and Safety Innovation. PolyU and University of Maryland from the US, jointly established CAiRS, combining AI and innovative technologies to improve product safety and system reliability. Our research is readily available and applicable to different industries (smart living, smart mobility, smart environment, advanced manufacturing, smart sensors & IoT and electronics & microelectronics) in Hong Kong. It comes with high potential Technology and Commercial impacts that contribute greatly towards the building of Smart City and Smart Manufacturing in Hong Kong.

Our research results are published in 13 international journals, and we have successfully filed 3 patents. In this issue, we highlight 15 of our research projects related to “Anomaly Detection and Syndromic Surveillances”, “Innovative Diagnostics for Health Management”, “Prognostics for Remaining Useful Life Assessment”, “Safety Assurance: Improve Functional Safety” and “Data Analytics Platform for Reliability”. CAiRS range of research applications is very wide. Some of these include robots, medical equipment, vehicles, telecommunications, consumer goods, public utilities, transportation, microelectronics, electrical installations, sensors, IoT products and other advanced manufacturing technology. Our research contribution is recognized by the industry with great appreciations.

We actively promote reliability and safety innovations by organizing technical seminars and webinars to create awareness on topics related to reliability and safety. CAiRS conducted a full-day technical seminar, “AI-based Reliability & Safety – Transforming Smart Manufacturing and Smart City with Applications”, on 19 May 2022.

This year, Prof. Michael Pecht, Director of Center for Advanced Life Cycle Engineering (CALCE) at the University of Maryland (UMD) and Head of Research Projects, visited CAiRS in November & December 2022. He had series of discussions with all Project Leaders and researchers, and presented in a topic titled, “Challenges in Product Reliability & System Safety”, in a public seminar organized by CAiRS on 3 November 2022.

“As you read our magazine, I hope you feel inspired to engage with us to create a more reliable and safer world. With this focus, I am confident that we will emerge from this time in our history as a stronger research center excelling in reliability and safety innovations.”

Our Events

CAiRS Soft Opening Ceremony

CAiRS is a collaboration between the Hong Kong Polytechnic University and Center for Advanced Life Cycle Engineering at University of Maryland, College Park, Maryland, USA and is under the InnoHK Research Cluster of HKSAR Government. Our mission is to develop new approaches using AI methodologies for customized management. This is to ensure the reliability and safety of products and systems used in various and a broad range of applications.

Thank you to all the premier guests participating in our ceremony on 29 Jun 2021 to share our memorable milestone. We look forward to future collaborations. With our dedicated research teams and many industry partners, we would contribute to the development of Hong Kong as a Smart City.

Press Conference

CAiRS organized a press conference on 29 Dec 2021 with a total of 47 different Press Media publications. With academics and scholars from the Faculty of Engineering of PolyU and UMD. Having research excellence and track records in product reliability and system safety, and with strong support from industry, CAiRS will bring significant benefits and contributions to Smart City development and Smart Manufacturing.

CAiRS InnoHK Launch Ceremony

The InnoHK Launch Ceremony was successfully held on 25 May 2022, marking a new milestone in the Hong Kong Special Administrative Region (HKSAR) Government's commitment to promoting Hong Kong's innovation and technology (I&T). As the flagship I&T initiative of the HKSAR Government, InnoHK aims to promote global research collaboration with a view to putting Hong Kong on the global advanced technology map. CAiRS is one of the 28 InnoHK research centres admitted under AIR@InnoHK Cluster.

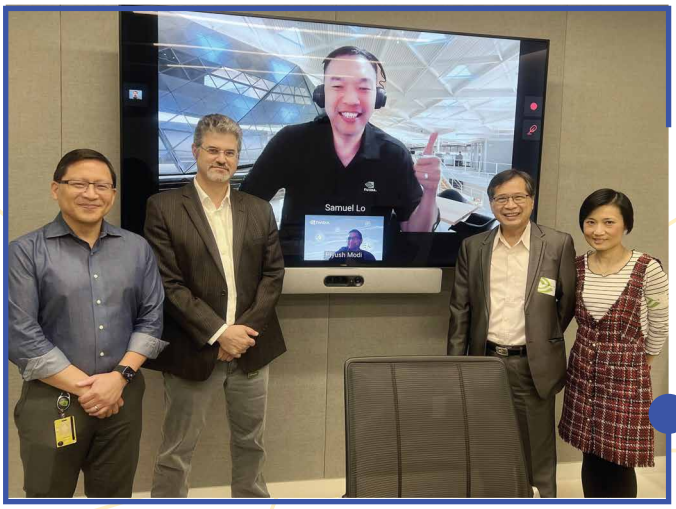
Official Launch of Microelectronics Technology Consortium, METC

CAiRS is one of the members of METC and we are delighted to attend their launching ceremony on 9 Nov 2022.

CAiRS Steering Committee Meeting

Members of our Steering Committee from PolyU senior management, Federation of Hong Kong Industries (FHKI) and Hong Kong Electronic Industries Association (HKEIA) held a fruitful meeting in Dec 2022.

US Trip: Nvidia Headquarters & University of Maryland (UMD)



CAiRS team visited Nvidia, our technological collaborator, at their headquarters in Santa Clara in Sep 2022.

They also met with UMD Senior Managements and conducted Management Meeting with UMD Team.

Our Seminars

(From left) Dr. Siqi Bu, Dr Daniel Lun, Mr. Steve Chuang, Ir Prof. K.K. Lee, Mr Hasan Gadjali, Ir Prof. Winco Yung

Technical Seminar - "AI-based Reliability & Safety – Transforming Smart Manufacturing and Smart City with Applications"

With the support of our honourable guests and speakers, over 100 participants attended the seminar on 19 May 2022. We invited 2 Guests of Honours (Mr. Steve Chuang, Chairman of FHKI & Ir Prof. H.C. Man, Dean of Engineering Faculty of PolyU), 4 speakers from industries (Mr. Aldous Leung - Senior Engineering Consultant of German Pool, Mr. Lok Fung - Head of Transit Management Competence Centre of Jardine Schindler Group, Ir Prof. K.K. Lee - Founder and CEO of KDAS & Mr. Hasan Gadjali, Co-founder of Meridian Innovation Limited), and 4 speakers from academics (Dr. Siqi Bu – Associate Professor of PolyU, Prof. Kenneth Lam – Professor & Associate Dean of PolyU, Dr. Daniel Lun – Associate Professor of PolyU & Dr. Xiaoge Zhang – Assistant Professor of PolyU). They are all professionals in Transforming Smart Manufacturing and Smart City with Applications in the context of reliability and safety by application of AI.

(From left) Mr. Aldous Leung, Dr. Xiaoge Zhang, Ir Prof. H.C. Man, Mr. Lok Fung, Ir Prof. Winco Yung

Over 100 participants attended the seminar

(From left) Prof. Michael G. Pecht, Ir Prof. Winco Yung, Prof. Kenneth K.M. LAM

Over 100 guests from the industries joined the seminar

Q&A session in the seminar

Public Seminar - "Challenges in Product Reliability & System Safety"

CAiRS public seminar titled "Challenges in Product Reliability & System Safety" was successfully held on 3 November 2022. In this seminar, we were honored to have two featured speakers (Prof. Michael G. Pecht & Prof. Kenneth K.M. Lam) who are world-renowned experts in Product Reliability & System Safety. Case studies in bare PCB and Li-ion batteries were presented and discussed.

Our Webinars

In the webinars, we invited overseas and local professional experts, and renowned industrialist to share their industrial and research experiences on product reliability and system safety. For more information, please visit our website at www.cairs.hk

(29 Jun 2021)

(27 Oct 2021)

(15 Dec 2021)

Our Online Lectures

UMD Online Lectures 2022

We organized a total of 16 online lectures with University of Maryland (UMD) in 2022, and over 800 participants attended the lectures.

Title	Date
Component reliability assessment based on modeling and testing	05-Jan-2022
Simulation-Based Modeling for Prognostics	19-Jan-2022
Digital twins for reducing testing and qualification needed for safety assurance: Is the microelectronics industry ready?	16-Feb-2022
The difficulty in duplicating field anomalies during laboratory post-mortems: A reliability physics perspective	23-Feb-2022
Reliability and Safety Analysis using Digital Twins	09-Mar-2022
Non-destructive methods of failure analysis	23-Mar-2022
Interpretability of Machine Learning Algorithms and Ensemble Learning Methods	06-Apr-2022
Product reliability validation for varying life cycle profile	20-Apr-2022
Prognostics-Based Qualification for Product Reliability Demonstration	04-May-2022
Potential of Augmenting Simulation-Based Component Reliability Assessment with Data-Driven Tools	01-Jun-2022
Fatigue Damage of Engineering Systems under Complex Vibration Environments	15-Jun-2022
Component Reliability Assessment Through Failure Mechanism Simulation	28-Sep-2022
Qualifications and Machine Learning	19-Oct-2022
Li dendrite formation in lithium-ion batteries - effects of battery materials	16-Nov-2022
Data-Driven Failure Analysis	30-Nov-2022
Thermal runaway in lithium-ion batteries - stages and causes	14-Dec-2022

Visitors to CAiRS

Hon. Duncan Chiu, a member of the Hong Kong Legislative Council for the Technology and Innovation functional constituency visited CAiRS on 20 Sep 2022.

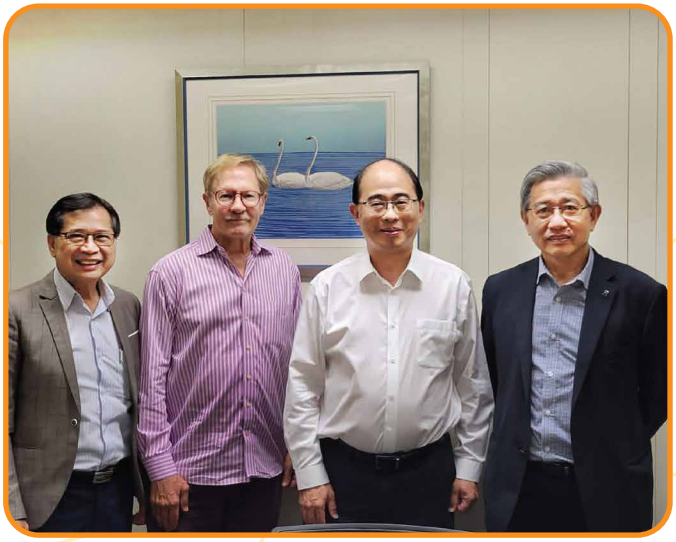
Ms Rebecca Pun, Commissioner for Innovation and Technology & her team visited CAiRS on 9 Sep 2021.

Professor Jin-Guang Teng, President of PolyU & senior management of PolyU visited CAiRS on 25 May 2022.

Dr. Miranda Lou, Executive Vice President of PolyU visited CAiRS on 10 Nov 2022.

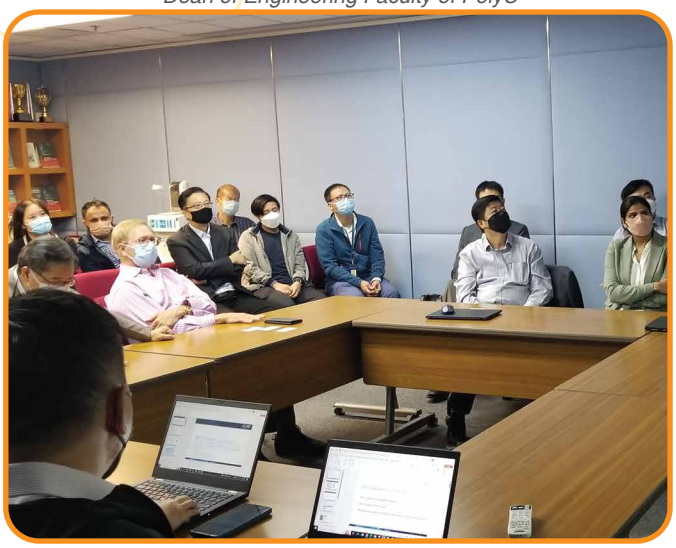
Professor Michael G. Pecht's Visits to CAiRS & Our Collaborators

During Prof. Pecht's visits to Hong Kong in Nov & Dec 2022, he exchanged insights with CAiRS' teams on both research projects and team building. He met with senior management from PolyU and the Hong Kong Electronic Industries Association (HKEIA). He also visited several CAiRS industrial collaborators to gain a better understanding of the industry's research needs on product reliability and system safety.



(From left) Ir Prof. Winco Yung, Prof. Michael G. Pecht, Prof. Wing-tak Wong, Deputy President and Provost of PolyU, and Ir Prof. H.C Man, Dean of Engineering Faculty of PolyU

CAiRS Team building Series –
Prof. Pecht gave a Cultural Talk to CAiRS staffs



Prof. Pecht discussed with CAiRS Project Leaders and their team of researchers.

Altai Technologies

ASMPT

GP Batteries

HK Electric

MTR

Meridian Innovation

The Hong Kong Electronic Industries Association (HKEIA)

Yau Lee Construction

Our Laboratories

We have our own laboratories and supercomputer that facilitate the data collection from a wide variety of components, products, or systems for our research projects. Below are some of the equipment and please visit our website for details.

HIGH PERFORMANCE COMPUTING

Supercomputer NVIDIA DGX A100

LIFE CYCLE ASSESSMENT

Powertester

LIFE CYCLE ASSESSMENT

Power Device Analyzer

LIFE CYCLE ASSESSMENT

Interrogator

TEMPERATURE & ENVIRONMENT TESTING

High Temperature Oven

LIFE CYCLE ASSESSMENT

Benchtop Vibration Table

LIFE CYCLE ASSESSMENT

Battery Charge/ Discharge Testing System

LIFE CYCLE ASSESSMENT

Shock Machine

TEMPERATURE & ENVIRONMENT TESTING

Temperature and Humidity Chamber

TEMPERATURE & ENVIRONMENT TESTING

Highly Accelerated Stress Test (HAST) Chamber

TEMPERATURE & ENVIRONMENT TESTING

Thermal Shock Chamber

FAILURE ANALYSIS

X-Ray Microscopy

FAILURE ANALYSIS

X-Ray Fluorescence Spectrometer

FAILURE ANALYSIS

Electrodynamic Tester

FAILURE ANALYSIS

Nanoindenter

FAILURE ANALYSIS

NEW!!

Scanning Acoustic Microscope

Anomaly Detection in Metal Components

The metal component is critical in the electromechanical switches. Scratches on their surfaces negatively influence the conductivity of the overhang trigger switch used in the high-power devices. This reduces the Remaining Useful Life (RUL) of the product and could be life-threatening to the user.

The objectives of this project are:

- To leverage the AI algorithm to detect anomalies on metal surface automatically by Data-Driven Modelling (DDM) methodology
- To provide a guideline to reduce the occurrence of component scratch thereby increasing the remaining useful life and reliability of the product in the mechanical production process

The benefits include:

- Component scratch anomaly root cause analysis
- Sensor selection and placement
- Component scratch failure mode detection
- Provision of advance detection and monitoring of anomalies
- Guidelines for the optimization of vibration feeder
- Improvement on product remaining useful life, reliability and safety

Metal Scratches

We have developed an AI-based living model of product system performance that collects and monitors data streams through the product's lifecycle from manufacturing to field use to disposal. To monitor manufacturing performance, we have developed an image capture system and a real-time scratch detection model to monitor the manufacturing process. To monitor the product performance from field use to disposal, an innovative prediction algorithm has been developed for predicting the RUL of the product.

We investigated and conducted the selection and placement of sensors. This will be deployed on the production line to capture component surface information to monitor any scratches that appear on components during manufacturing processes. We also designed and implemented an end-to-end deep learning-based model to automatically identify the location of components and classify whether the components are defective or normal.

Experimental results show that our proposed solution can significantly improve the recall rate for the component defects in the production line, thus effectively reducing device malfunction.

Early Detection of Degradation in Electronic Interconnects

Bad connectivity of the interconnects at the solder joints will create some safety or reliability concerns about the Remaining Useful Life (RUL) of products, as well as during the use of the products. Computer vision systems, such as Automated Optical Inspection (AOI) are commonly used in the production line but only for the final product instead of during the soldering process.

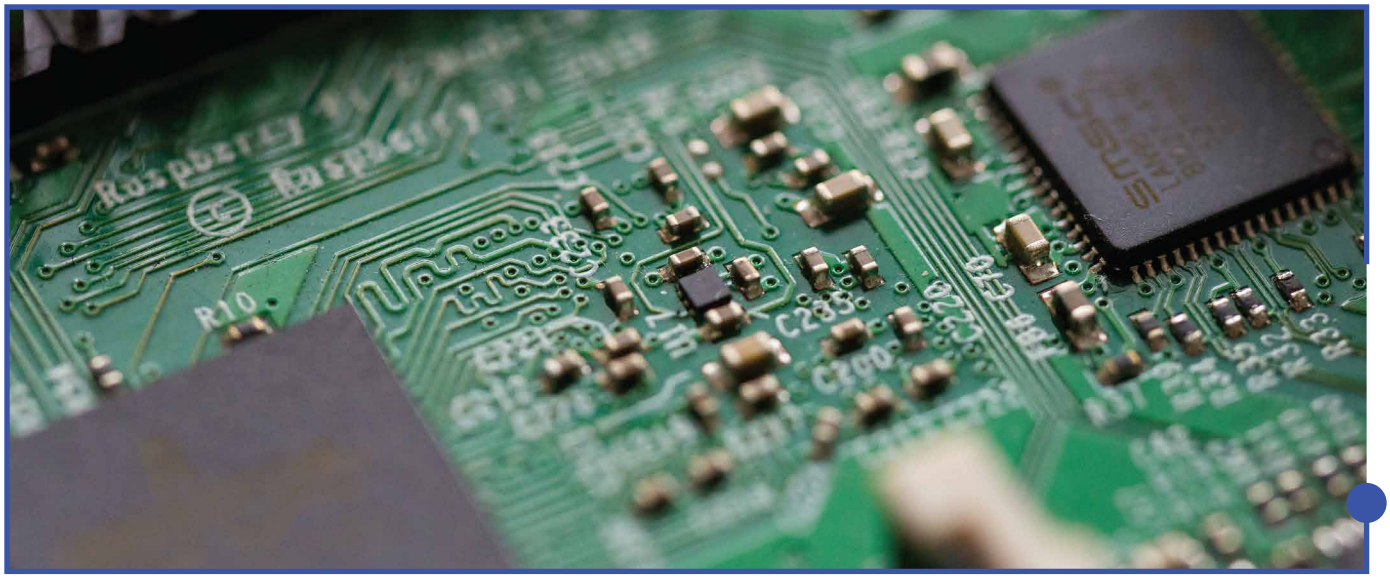
The objective of the project is to determine the feasibility of early detection of degradation in electronic interconnects using Data-Driven Modelling (DDM) and Physics of Failure (PoF) Analysis.

The benefits include:

- Analysis of the root cause of PCB soldering defects
- Development of PCB soldering defect detection and classification algorithms
- Prediction of the Remaining Useful Life (RUL) of modules/ components
- Provision of advanced real-time detection and monitoring of PCB soldering anomalies
- Reduction of PCB soldering defects in the production process
- Improvement in product reliability and safety

We have developed a non-destructive canary system based on a thermal imaging camera for the detection of PCB soldering failure mechanisms under high current usage. This can perform an early detection of solder joint failure mechanisms on the production line. At the same time, we have also proposed an AI-based solder joint failure prediction model based on the limited data collected by the canary system.

Experimental results show that our proposed canary system can effectively detect the failure mechanisms of solder joints.



Detection of PCB Soldering Anomalies

Early Detection of Degradation in Rail Track System

Rail Inspection System is used to provide real-time track image recording and condition monitoring, including detection, dimensional measurement, classification and location reporting of rail cracks and defects automatically.

The objective of this project is to apply the most advanced deep learning technology to enhance the intelligent transportation system's reliability and safety. Such application can effectively reduce the risk caused by faults in operation and improve operational efficiency.

In this project, an end-to-end deep learning-based model (data-driven model) was employed for health monitoring of the rail track system. Preliminary experimental results show that our proposed solution can effectively improve the reliability and safety of the rail track system.

Rail Track Defects

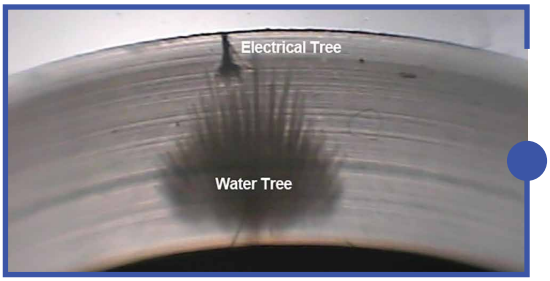
Adaptive Diagnosis of Water Tree in Medium Voltage Underground Cable using Transfer Learning and Simulation-based Analysis to assess Cable Condition and predict Remaining Useful Life (RUL)

Water tree development problems can lead to breakdown in electric cable insulation, which may occasionally affect the overall system reliability for power distribution. Water tree in electrical cable is a tree-like pattern of electro-oxidation that can occur at stress enhancements such as ionic contaminations, protrusion, or voids in polymeric materials subjected to electrical stress and moisture. It is a slow process, usually taking years to penetrate the insulation from the inside or outside. There is a need to diagnose water tree development in order to prevent breakdown in cable insulation.

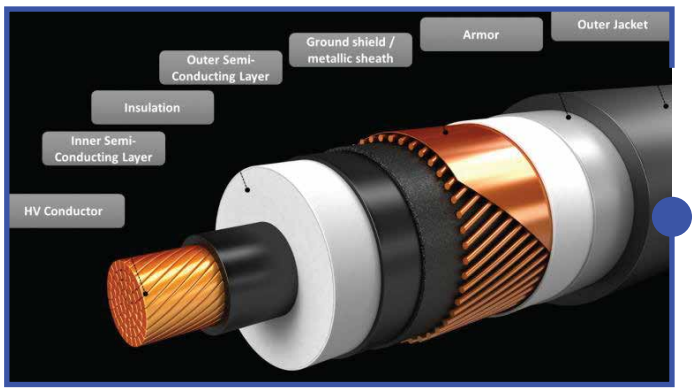
The objective of the project is to enable adaptive diagnosis of water tree in medium voltage underground cable using transfer learning and simulation-based analysis to assess the cable condition.

The benefits include:

- Estimation of Remaining Useful Life (RUL) of underground cable
- Optimization of scheduled maintenance
- Reduction of unplanned underground cable replacement works
- Improvement on power supply reliability
- Improvement on the classification of cable health index



In this project, transfer learning and simulation-based techniques have been used to determine the water tree locations, severities, and cable's RUL. Experimental results show that our proposed solution can significantly reduce water tree related cable faults and effectively forecast the cable's RUL for scheduling just-in-time maintenance.



Water Tree Defects in Underground Electric Cables

Individualized Fault Diagnosis and Predictive Maintenance for Bus Engine Cooling System by Ensemble Methods

Bus engine overheating incidents due to the breakdown of various sub-systems or components (e.g., thermostat) will eventually resulted in service disruption on the road. This could lead to complaints from passengers and difficulties in fleet management. An engine cooling system in bus vehicles comprises many sub-components including thermostat, water pump, radiator, cooling fans and pipes. Failures would lead to engine overheat and vehicle breakdown on the road.

The objectives of this project are:

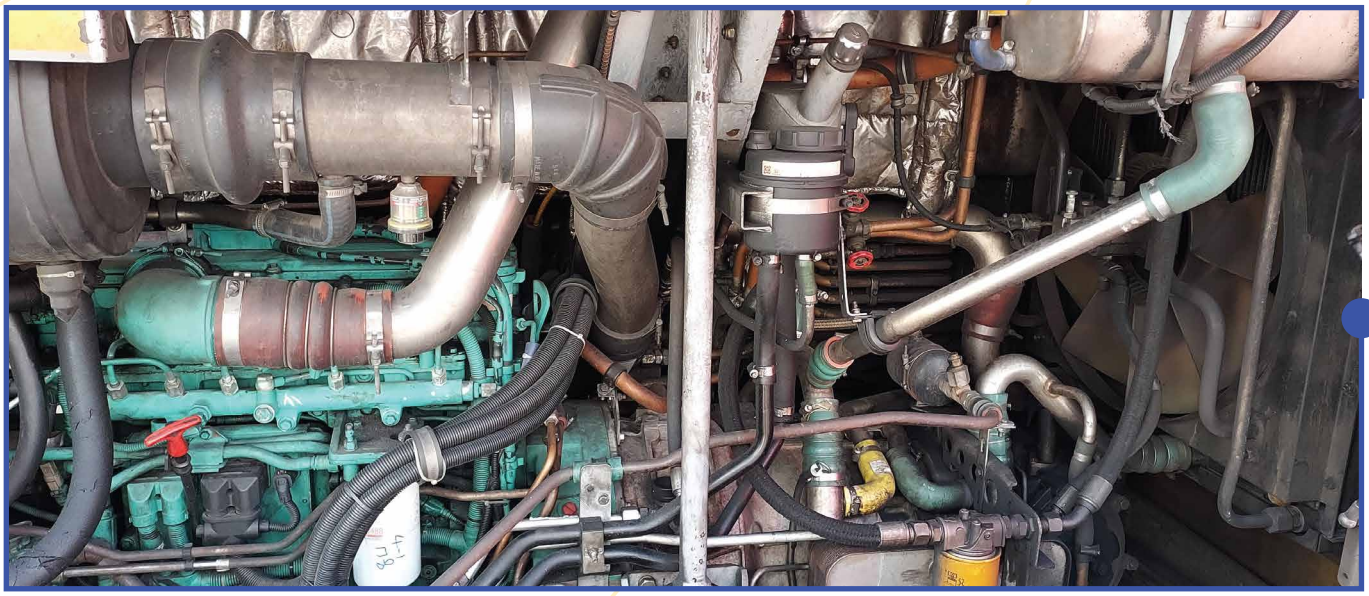
- To determine suitable sensor(s) for installation
- To install suitable sensor for data collection
- To develop Machine Learning (ML) model to diagnose anomalies of the bus engine cooling system

The benefits include:

- Reduction of breakdowns of buses during service operation
- Improvement on service reliability and availability

In this project, the thermodynamic principles of the Engine Cooling System, Coolant Temperature, Fuel Rate, Air Temperature and Fan Speed have been studied and identified as the key parameters associated with the health status of the system. Fault diagnosis with AI ensemble methods for predictive maintenance was applied.

Experimental results show that our solution successfully reduced component field failure and the corresponding cooling system on-the-road service disruption.



Fault Diagnosis for Bus Engine Cooling System

Development of Canaries for Failure Prevention for Li-ion Batteries

When Li-ion cells were cycled at certain charge/ discharge conditions, it was observed that abnormal cell swelling could occur and might lead to potential disintegration of cells. There is a need for early indication of the abnormal swelling problem, and hence develop methods to prevent the occurrence of the failure.

The objective of the project is to apply fiber Bragg grating (FBG) sensors as canary (a device that provides an early signal of failures/ anomalies) for detecting the abnormal swelling of the Li-ion cells and assessing their Remaining Useful Life (RUL) and/ or other critical parameters (e.g., incremental capacity analysis, incremental strain analysis, etc.).

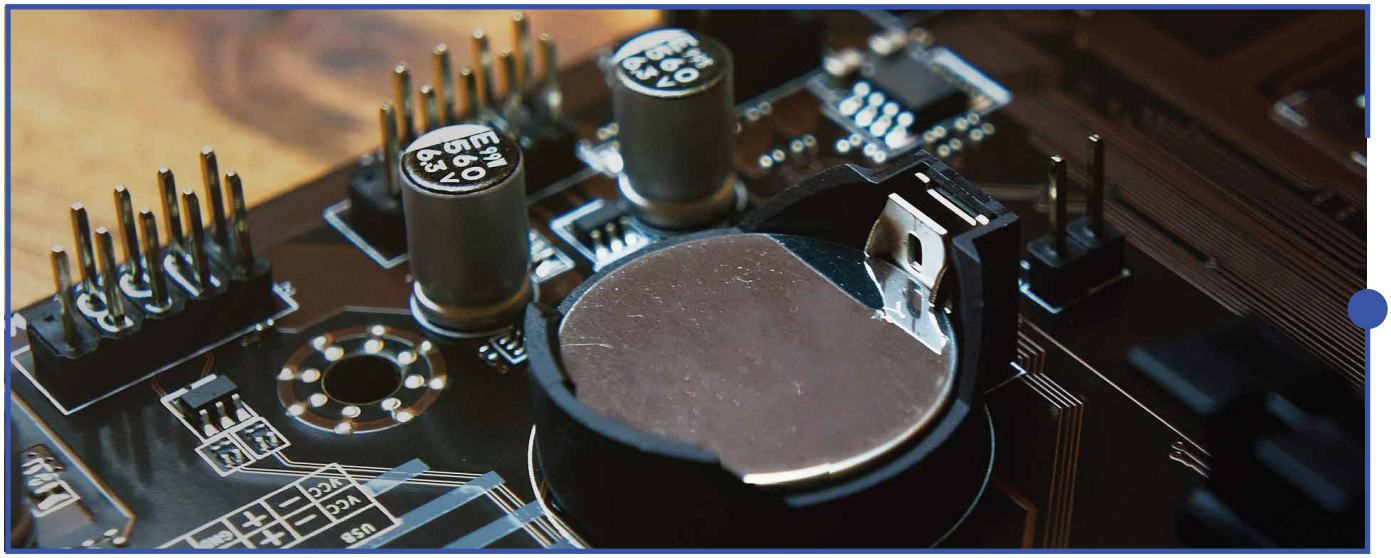
The benefits include:

- Provision of advance warning of abnormal cell swelling
- Improvement on reliability of cell
- Prediction of Remaining Useful Life (RUL) and/ or other critical parameters

Conventional approach in determining the usable life of battery cells is by extrapolating accelerated test results at worst-case temperatures in laboratories. However, due to the inherent uncertainties in operating environment factors (i.e., C-rates and temperatures), the lifetime of a battery might be substantially different from the lifetime measured under the controlled conditions in laboratories.

In this project, we successfully employed sensors as canary devices that can be applied on the cell to measure the strain and temperature in real time. Its health conditions can continuously be monitored for better in situ assessment of remaining useful life.

Experimental results show that test time for detecting anomalies before failure can be significantly reduced and risky batteries can be effectively sorted out.



Failure Prevention for Li-ion Coin Battery

Prognostic and Health Management (PHM) of FGD Plant Booster Fan Motor for Forecasting Maintenance and RUL Prediction

To reduce the pollutants emission in the power industry, a dedicated desulfurization system was installed to exclude Sulphide generated during coal combustion. An induction motor was identified as the critical component of the system.

The objectives of this project are:

- To perform diagnostic of the FGD induction motor, and
- To predict Remaining Useful Life (RUL) of the FGD induction motor through Data-Driven Modelling (DDM)

We have developed a motor simulation model based on the FGD induction motor, a data acquisition system with a visualization platform for collecting motor data and fault diagnosis, and an AI-based algorithm to assess the extent of deviation or degradation for motor and RUL prediction. These can minimize unscheduled maintenance, extend maintenance cycles, and maintain effectiveness through timely repair actions.

Experimental results show that early malfunction symptoms can be effectively detected and hence frontline engineering hours on corrective maintenance works and emergency actions can be reduced.

Prognostic & Health Management of Flue Gas Desulfurization (FGD) Motor

Use of Failure Models for Real-time Failure Prediction and Uncertainty Management of Power Module

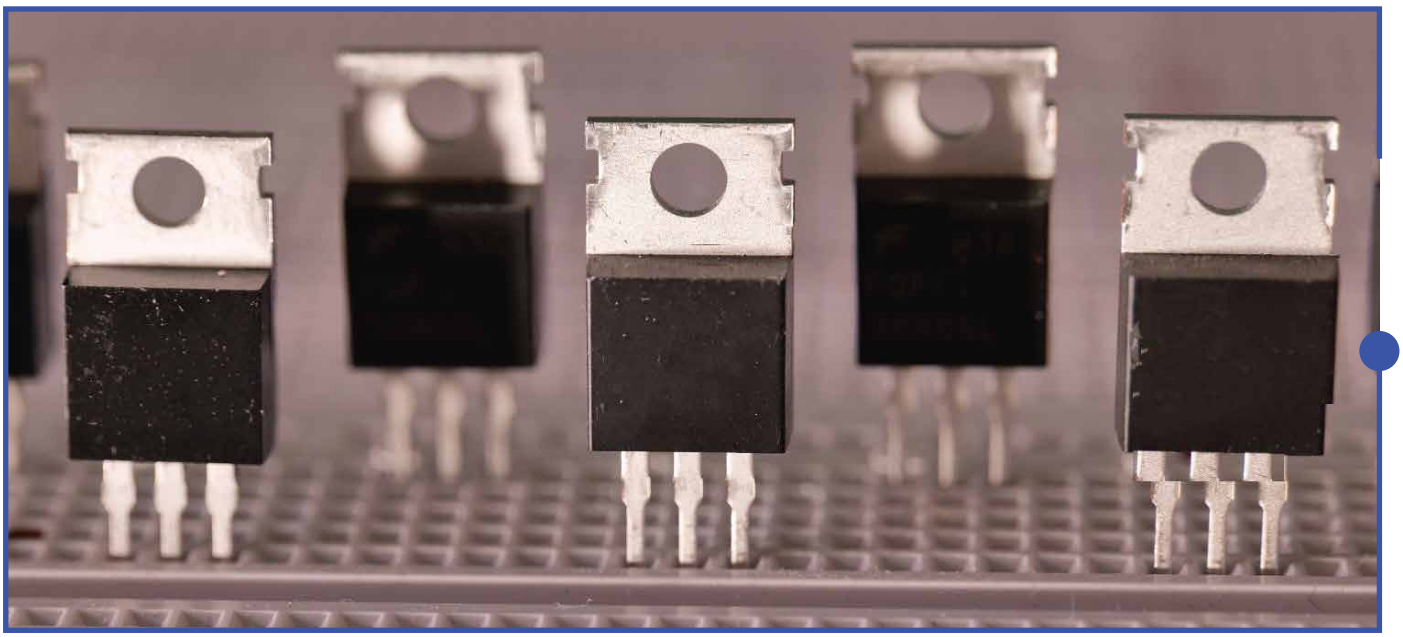
The lifetime of power devices in an equipment or system always limits the failure rate of the entire system. Power MOSFET is a critical component in motor drivers of equipment, its failure rate can be reduced by on-time monitoring of power MOSFET.
With reliability methodologies and tools, we can study the physics of failure, failure modes and mechanisms of power MOSFET. Using AI modeling, we can predict the remaining useful life (RUL) of power MOSFET for predictive maintenance.

The objectives of this project are:

- To find out the Physics of Failure (PoF), failure modes and mechanisms of critical components, and
- To give advance warning of failure for Remaining Useful Life (RUL) prediction of critical components of electronic devices/ products

In this project, a systematic accelerated degradation test based on power cycling was designed and performed, using an advanced power tester and a power device analysis machine to access the degradation and failure precursors of power MOSFETs. A comprehensive failure precursors data is collected and analyzed. The experiment further permits the exploration of additional reliability information, such as failure modes, mechanisms, effects as well as Remaining Useful Life (RUL) prediction of power devices such as MOSFETs.

Experimental results show that equipment malfunctions for power MOSFET-related failures are effectively reduced, and reliability prediction can be achieved.



Modelling of Power MOSFET Failures

Investigation of the Health, Degradation, and Aging Mechanisms of Steel Wire Rope used in Lift Systems

Lifts are devices with high safety requirements. Improve lift safety ensures the operations of assets and reduces the risk of sudden failure that may cause serious injuries or even death. Lifts require effective and appropriate maintenance strategies to maintain their functional operation.
Steel wire rope is one of the critical components of the lift system, and its failure can result in serious injuries or even death. The maintenance and replacement of steel wire rope currently heavily rely on manual inspection, using visual inspection and calipers to check the condition of the steel wire rope. The existing method is less reliable and cannot observe possible internal defects of the rope.

The objectives of this project are:

- To perform Physics of Failure (PoF) analysis on steel wire ropes to determine the sensor required
- To install the sensors for data collections
- To develop Machine Learning (ML) techniques for detecting and recognizing steel wire rope defects

The benefits include:

- Reduce the risk of lift failure to an acceptable level and reduce testing time
- Improve service reliability and availability
- Improve function safety and safety integrity level according to IEC 61508 standards

CAiRS has studied inspections of wire ropes using Non-Destructive Testing (NDT). Sensors can be installed in lift system without disruption of operation. This helps reduce dangerous undetected failures per hour in continuous mode of operation [i.e., increasing redundancy] to improve Safety Integrity Level (SIL).

Through the forgoing step, diagnostic coverage and the detectability of steel wire rope defects are greatly improved. CAiRS has developed an AI-based detection model which can improve the detectability of broken wires compared with the manufacturer's algorithm hence improving test efficiency during inspections.

Detection & Diagnosis of Steel Wire Rope Defects

AI-based E&M System Safety with IoT by Hybrid Strategy: Physics of Failure (PoF) Analysis and Data-driven Modelling (DDM)

In recent years, lifts have been used increasingly in apartments, commercial facilities, and office buildings located in urban areas, in which more than 54% of the world's population is living. Therefore, proper maintenance of lifts is crucial to ensure their safety and reliability. Currently, the maintenance of lifts is based on corrective and/ or condition-based maintenance. However, these types of maintenance approaches can be costly and cannot ensure the prevention of sudden breakdown of the lifts. In view of this, predictive maintenance is proposed to reduce repair cost and increase the lifetime while maximizing the uptime of lifts.

The objective of this project is to assess normal and degraded conditions of lift system with consideration of loading conditions by means of Physics of Failure (PoF) analysis and Data-driven Modelling (DDM).

The benefits include:

- Identification of the cause leading to lift's degradation
- Examination of suitable DDM approach
- Detection of lift's anomaly

In this project, various loads and conditions of E&M system, i.e. lift, and their impact on useful life was being studied. AI approach was trained and tested with the industrial data collected from bearings of E&M systems and open-source data under various loads and conditions. Analytical methods related to the impact of the useful life has also been studied. In which, health indicator could reflect the current health conditions of E&M system, and construction of health indicators is regarded as the key to predicting the remaining useful life.

Experimental results show that our solution can effectively reduce repair cost and increase the lifetime while maximizing the uptime of lifts by predictive maintenance methodology.

AI-based Lift Safety System

AI-based Safety Assurance for ABS-related Plastic Product by Computer Vision with Data-driven Modelling (DDM) Approach

Accidental assembly and installation of the defective ABS-related products can lead to serious safety issues when the vehicle is in operations. There is a need to minimize the production of defective ABS-related products and trace back to the root causes in the manufacturing process parameters.

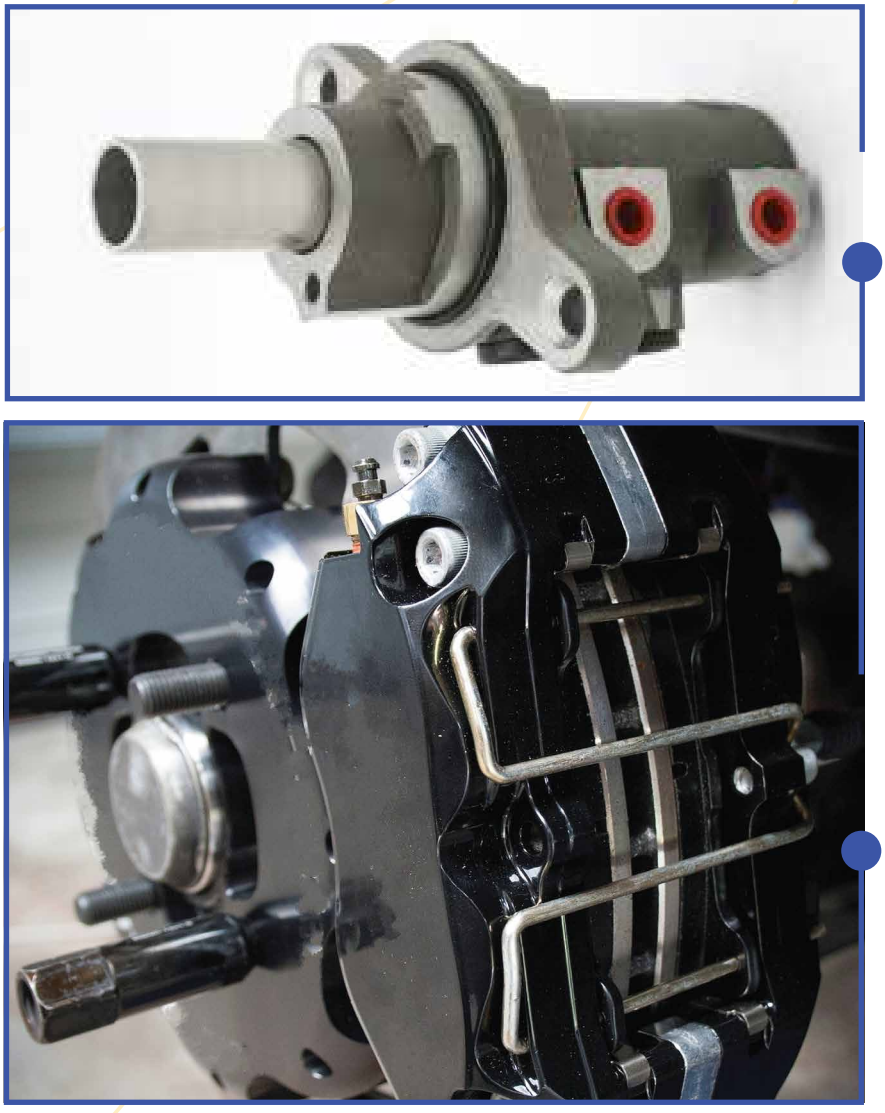
The objective of this project is to determine the safety assurance of ABS-related products by detecting the defective products by computer vision with Data-driven Modelling (DDM) approach.

The benefits include:

- Determination of suitable computer vision method
- Determination of suitable DDM approach
- Detection of defective products

Four defects related to the change in geometry (break, shrinkage, burn mark, and missing pin) were identified as areas of research focus in this project. It can be noted that these defects are different in characteristics, and they will affect the integrity of the products, and ultimately compromise the vehicle's safety.

To minimize the rate of defective products, we developed a hybrid approach that integrates data-driven modelling (DDM) with the physics of failure (PoF). In this approach, DDM is exploited in two respective areas. The first one is to leverage computer vision techniques to detect defective products, and the second one is to analyze the manufacturing process parameters to identify root causes leading to defective products. Experimental results show that our solution can successfully improve the component reliability and ensure vehicle safety.



Safety Assurance of Plastic Products in Vehicle Anti-lock Braking System

Functional Safety for Lift Systems that implement AI

Current editions of functional safety standards do not allow usage of AI to carry out safety-critical functions because of the lack of their transparency and analytical methods. As is known, the adoption of AI in safety-critical domain still stays in exploratory status that the assessors and practitioners appear prudent to convince the broad utilization of AI technology. It has been discovered that the current international regulation as IEC 61508:2010 standard does not recommend the utilization of AI technology with the main concern on its capability of transparency and interpretability of its functional behaviors, which is called the “Black Box” operation.

The objective of this project is to monitor the health conditions of lift safety-related system/ subcomponent by developing and implementing Artificial Intelligence (AI) to meet safety requirement.

The benefits include:

- Explore the risk of lift safety-related system/ subcomponent
- Condition monitoring of the system/ subcomponent by utilizing of AI with alert generation
- Enable lift safety-related system/ subcomponent maintained under healthy condition by AI-powered solution

A systematic project implementation framework has been devised by combining both theoretical research with practical applications with industrialization. This project is used to establish the smart condition monitoring system for elevators with enhanced safety and reliability.

Regarding the AI analytical model, we have adopted the deep learning algorithm with the devised novel architecture to capture the latent features from the input samples from the core measured components. With research to enhance the data transparency, we have utilized multiple data visualization methods to convert and depict the multi-variant current signals into visualized figures to reflect the fluctuations of current during lift’s operation. With CAiRS solution, functional safety beyond the lowest Safety Integrity Level (SIL) applications can be enhanced.

AI-based Functional Safety for Lift System

Train Track Remaining Useful Life (RUL) Modelling

Railway track is one of the safety critical components in the railway system. Daily usages can lead to the degradation, such as the occurrences of track defect and geometry defect. Track degradation may reduce the stability of the train passage which leads to severe incidents, such as derailment. Regular inspections and maintenances are required to keep the tracks in safe condition for train operation.

Various routine inspections, such as visual inspection and track inspection vehicle, can be conducted to determine the track conditions and serviceability. However, these inspections are defect-specific, meaning that each inspection can only partially determine the track condition, a combination of inspections are needed to determine the complete track condition. These inspections are time-consuming, labor-intensive and can only be conducted during Non-Traffic Hours (NTH), therefore frequent inspections for all defect types are not practical in terms of resources. The lack of this complete track condition may lead to delayed track maintenances if the track degradation rate is faster than expected. A delayed track maintenance may lead to track failure which reduces the reliability and safety of the railway system. To enhance the Prognostic Health Management (PHM) of train track, RUL modelling that indicates the complete status of the track is of prime importance that drives track reliability and train operational safety.

The objective of this project is to develop a Predictive Health Management of train track system. This work is to safeguard the reliability and safety issues on track and minimize the reliability and safety risk in a railway system. The benefits include:

The benefits include:

- Leverage on Fiber Bragg Grating sensor data and AI methodology to assess train rail condition
- Safeguard the reliability and safety issues on track (train derail, collision, schedule delay)

Modelling of Train Track Degradations

Video Camera Anomaly Detection

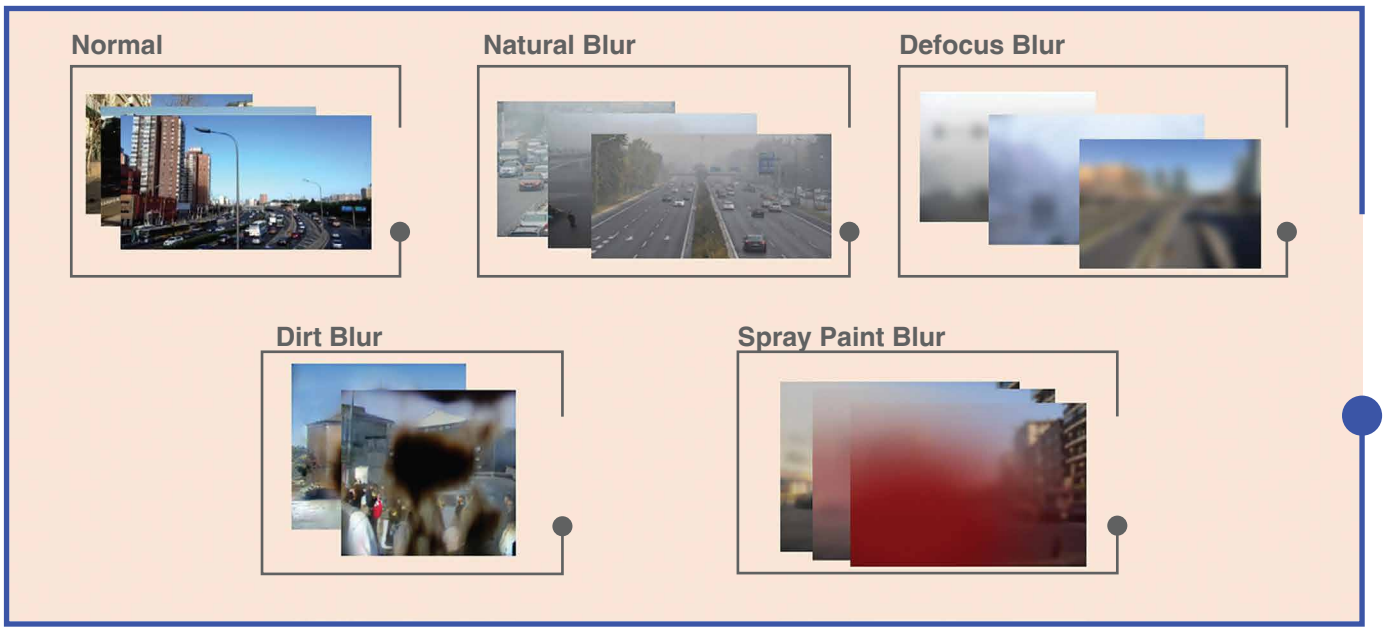
In the Hong Kong Chief Executive's 2020 Policy Address, it was announced that more than 130 smart city initiatives in the Smart City Blueprint for Hong Kong 2.0 would be released in 2020. Many of these initiatives are related to smart monitoring and surveillance, which rely on the videos captured by different smart cameras installed in the city. Besides smart surveillance mechanisms, many Internet-of-Things (IoT) systems also make use of video information to make the decision at the edge. The quality of these videos becomes important as wrong decisions will be made with low-quality videos. Unfortunately, many surveillance cameras are installed in outdoor locations, and their performance will degrade after years of operation. Besides, they can also be tampered with by intruders due to different reasons. It is required to carry out a regular check for these surveillance cameras to guarantee the quality of the videos captured. However, these surveillance cameras are installed in locations that are often difficult to access. It makes their maintenance become difficult and costly.

The objective of this project is to develop an automatic fault reporting system for surveillance cameras by detecting the anomaly in the captured video using an AI deep learning approach.

In this project, we developed an automatic video anomaly detection system using the artificial intelligence (AI) technique. The system allows real-time detection of four blur anomalies in surveillance videos. They include natural blur caused by different environmental factors (e.g. foggy, raining), defocus blur due to camera aging, dirt blur owing to the dirt on the camera lens, and spray-paint blur resulting from the tampering of intruders.

We synthesized/collected the dataset Blurveillance and used it to train the proposed deep learning model for blur anomaly detection. The Blurveillance dataset contains ten thousand images with five classes of surveillance images (normal, natural blur, defocus blur, dirt blur, and spray-paint blur). Different image processing and deep learning techniques were used for image synthesizing.

Our proposed model replaces manual work, enables real-time anomaly detection and successfully reduces field service or video surveillance down time.



Camera Blur Anomalies

Train Track Maintenance Intelligence System

Train track system has irregularity which is hard to be detected and categorized across the chainage. Hence, it is difficult to do rail predictive or prescriptive health maintenance in rail operation for enhancing transportation system reliability and safety.

Train track maintenance intelligence extraction relies heavily on the nature, quality, timeliness of data, it is impractical to conduct decision support system platform requirement based on end users' points of view. The reason is that the result generated from data through data-driven modelling or data mining is non-deterministic in nature. This is especially if the requirements of traditional decision support systems are predefined by the end-users who may not even know what useful intelligence can be mined from data. CAiRS researchers, therefore, apply innovative methodology to build the platform illustrating valuable maintenance and repairment information for reliability and safety of the rail system. This facilitates rail prognostic health management with the Remaining Useful Life (RUL) modeling and anomalies detection.

The objective of this project is to build intelligent decision support platform that provides aspects of application usages data literacy for maintenance stakeholders.

The benefits include:

- Open architecture blueprint with business/data/application/technology architectures defined for the platform
- Data visualization technique developed on platform to support the diagnostic and prognostic health management of train rail system
- Facilitate rail maintenance operator to visualize rail decision support intelligence that is not limited to rail anomaly detection or remaining useful life

Decision support system for train rail operation is highly complex in data format, structure, varieties, versatility, and dimensionality. Developing a decision support platform to visualize valuable and effective indicators (or indices) by using traditional enterprise software development for train rail is not one-size-fit-all

CAiRS researchers developed a train track maintenance intelligence decision support system to demonstrate a cloud end-to-end technology that starts from data ingestion, storage, data modeling, to data visualization.

Train Rail Maintenance

Publications

Journals

1) Yeung, C. C., & Lam, K. M. (2022). Efficient Fused-Attention Model for Steel Surface Defect Detection. IEEE Transactions on Instrumentation and Measurement.

2) Aziz, S., Faiz, M. T., Adeniyi, A. M., Loo, K. H., Hasan, K. N., Xu, L., & Irshad, M. (2022). Anomaly Detection in the Internet of Vehicular Networks Using Explainable Neural Networks (xNN). Mathematics.

3) Qais, M. H., Loo, K. H., Liu, J., & Lai, C. M. (2022). Least Mean Square-Based Fuzzy c-Means Clustering for Load Recognition of Induction Heating. IEEE Transactions on Instrumentation and Measurement.

4) Bonefacino, J., Ghashghaie, S., Zheng, T., Lin, C. P., Zheng, W., BLANQUER, L. A., ... & Boles, S. T. (2022). High-Fidelity Strain and Temperature Measurements of Li-Ion Batteries Using Polymer Optical Fiber Sensors. Journal of The Electrochemical Society.

5) Zhou, T., Zhang, X., Droguett, E. L., & Mosleh, A. (2022). A generic physics-informed neural network-based framework for reliability assessment of multi-state systems. Reliability Engineering & System Safety.

6) Zhang, G., Zhang, J., Liu, K., Guo, J., Lee, J., Hu, H., & Aggarwal, V. (2022). DUASVS: A Mobile Data Saving Strategy in Short-form Video Streaming. IEEE Transactions on Services Computing.

7) Zhang, G., Liu, K., Hu, H., Aggarwal, V., & Lee, J. (2021). Post-streaming wastage analysis a data wastage aware framework in mobile video streaming. IEEE Transactions on Mobile Computing.

8) Ye, Q., Wang, L. W., & Lun, D. P. (2022). SiPRNet: End-to-End Learning for Single-Shot Phase Retrieval. Optics Express.

9) Xu, Z., Lee, C. K. M., Lv, Y., & Chan, J. (2022). Ensemble Capsule Network with an Attention Mechanism for the Fault Diagnosis of Bearings from Imbalanced Data Samples. Sensors

10) Wang, Y., & Chung, S. H. (2021). Artificial intelligence in safety-critical systems: a systematic review. Industrial Management & Data Systems

11) Zhang, G., Lee, J. Y., Liu, K., Hu, H., & Aggarwal, V. (2021). A Unified Framework for Flexible Playback Latency Control in Live Video Streaming. IEEE Transactions on Parallel and Distributed Systems

12) Liu, T., Zhang C., Lam, K.M., Kong, J. (2022), Decouple and Resolve: Transformer-based Models for Online Anomaly Detection from Weakly Labeled Videos. IEEE Trans. on Information Forensics and Security.

13) Zhang, G., Zhang, J., Liu, Y., Hu, H., Lee, J., & Aggarwal, V. (2022). Adaptive Video Streaming with Automatic Quality-of-Experience Optimization. IEEE Transactions on Mobile Computing.

Patents:

I.) 监控摄像机异常检测系统和方法 System and Method for Surveillance Camera Anomaly Detection
PRC Invention Patent Application No. 202211032284.3

II.) 车辆节温器异常检测方法及系统 System and Method of Anomaly Detection of Thermostat in a Vehicle
PRC Invention Patent Application No. 202211063009.8

III.) System and Method for Spray Paint Image Synthesis in Surveillance Camera Anomaly Detection
Hong Kong Short Term Patent Publication No. 30076502 A

IV.) Bidirectional Spectral-based Transformer for Remaining Useful Life Prediction
Hong Kong Short Term Patent Application No. 32022066346.4

Industry Sharing

ASMPT

Mr. Peter Ng – Vice President

"ASMPT is a leading global supplier of semiconductor assembly and packaging solutions. We have developed cutting-edge solutions that can be applied to different end-user market items. Today, ASMPT's business has spread all over the world. We have 12 R&D centers and 13 production bases, of which Hong Kong is the largest R&D center in the world. We choose the reliability of power devices as our research focus because ASMPT is a power device packaging equipment manufacturer. Furthermore, we utilize a large number of power devices in our products. Therefore, we understand that the reliability of power devices is critical to the performance of ASMPT products. **The collaboration with CAiRS, and the help of their advanced experimental equipment can assist us in collecting data for analyses and discovery of the characteristics of power devices before possible failure. This is done using AI to build a data model to predict the reliability and lifetime of power device.**"

GP Batteries International Limited

Mr. Victor Chong – President

"Certainly, it's a pleasure for me to have this discussion with you regarding CAiRS and we have high hopes for the collaboration for both sides I believed. On GP batteries' side as well as for CAiRS, I think we have opportunities to make some breakthrough and new discoveries together. I am confident that we are going to make a leading age, discoveries and learning and breakthroughs from what we learn, we are going to put that back into business. And I think we are going to have some breakthroughs with this better understanding of our own battery system. **The advantages that we have is really the new methodologies and the expertise of bring together where the battery experts with CAiRS is the safety and reliability experts and in terms of the sensing technology, we are going to learn a lot together.**"

The Hongkong Electric Company, Limited

Ir Tony Yeung – Head of Construction & Maintenance

"With a history of more than 130 years, HK Electric has supplied electricity to Hong Kong Island, Lamma Island & Ap Lei Chau since 1890. It is one of the oldest electric power companies in the world. Since 1997, our power supply reliability has reached a world-class level of 99.999% or above. Underpinned by our core value of "Pursuit of Excellence", we hope to continue to provide our customers with a safe, reliable, environmentally friendly, and affordable electricity supply. Our collaboration with CAiRS is a typical example of how HK Electric strives for excellence and uses new technologies to help promote Hong Kong as a sustainable Smart City. In the process of transmission and distribution, we mainly use cables as transmission and distribution facilities. The cables themselves are very reliable. However, as being buried underground, they are easily affected by other road construction works. Once the cable is damaged, its dielectric strength gradually decreases and causes breakdown and it will finally lead power outage. Accurately judging the operational status and health index of the cables is a very big challenge. **We are very pleased to collaborate with CAiRS by using CAiRS' expertise in AI to collect and analyze cable operation data and using the data to develop health indicators and management models. Through this health index and management model, our colleagues can formulate inspection and maintenance plans in a timely manner. It is of great help in improving the reliability of power supply.**"

Meridian Innovation Limited

Mr. Hasan Gadjali – Co-Founder & COO

"Meridian Innovation aims to create a new consumer thermal imaging sensor. When used with AI technology, it can detect persons and differentiate life objects. It can also sense the invisible in the dark. In our daily life, we have an obligation to improve health and environmental safety. If such high quality and reliability is a must, CAiRS has the right expertise and equipment. This motivates us to work closely with them to bring our products to international standards. Meridian Innovation focuses on the global market and possess international standards and quality products required by first-tier customers. **By collaborating with CAiRS, we could perform reliability test on our products to ensure that the quality can meet customer expectations. CAiRS provides one-stop shopping. They not only performed reliability test to our product but also supported after-test analysis and let us understand the weak point of our product. This is helpful for the continuous improvement of products.**"

RaSpect Intelligence Inspection Limited

Mr. Harris Sun - CEO & Founder

"RaSpect and CAiRS share a common philosophy. Our common focus is on safety and reliability. In particular, RaSpect is engaged in intensive development in building inspection. We hope that through the collaboration with CAiRS, we can apply CAiRS' capabilities and their R&D team achievements to our platform and realize our company developmental aims. *We are now concentrating on the lift inspection and CAiRS is to deliver R&D results in the following three aspects: (i) lift current, (ii) lift bearing operation and (iii) lift position. These three aspects are very important for the daily lift safety assessment. Through the R&D results from CAiRS, we can extract and analyze the lift data in these three aspects, thereby giving us an evaluation of the daily lift operation and providing us reliability results as well as predictive analytics. It is believed that the industry has initially gained considerable recognitions in this regard. We hope to extend our focus to the entire community and not just limited to lift applications but to other fields. There are also AI solutions for safety and reliability available to the industry."*

Letter of Appreciation


Defond


German Pool


iRobot


KDAS


Kenta


Meridian Innovation


MTR


RaSpect

Sponsorship

Yau Lee Construction Company Limited sponsored an amount of HK$ 200,000 to CAiRS for research projects.

Ir Professor Winco K.C. YUNG
Executive Director & Centre Director
Centre for Advances in Reliability and Safety

RESEARCH PROJECT LEADERS (THE HONG KONG POLYTECHNIC UNIVERSITY)

Professor Steven BOLES (EE)
Adjunct Professor

Dr Nick S.H. CHUNG (ISE)
Associate Professor and Associate Head (also Associate Director of Studies, IGDS)

Professor Francis C.M. LAU (EIE)
Professor

Ir Dr Daniel P.K. LUN (EIE)
Associate Professor & Associate Head

Dr Siqi BU (EE)
Associate Professor and Associate Head

Dr Haibo HU (EIE)
Associate Professor

Dr Carman K.M. LEE (ISE)
Associate Professor

Professor Edward C.S. CHUNG (EE)
Professor

Professor Kenneth K.M. LAM (EIE)
Professor & Associate Dean, Faculty of Engineering

Dr K. H. LOO (EIE)
Associate Professor

Dr Xiaoge ZHANG (ISE)
Assistant Professor

RESEARCH PROJECT LEADERS (UNIVERSITY OF MARYLAND)

Professor Michael PECHT
Head of Research Programs

Professor Abhijit DASGUPTA

Professor Peter SANDBORN

Dr Michael AZARIAN

Professor Hassan KHAN

Dr Diganta DAS

Dr Michael OSTERMAN

Dr Robert UTTER

MANAGEMENT

Ir Clement LI
Chief Operating Officer

Dr Gary WONG
Assistant General Manager

Dr Tom CHAN
Senior Programme Manager

Dr Denny LAI
Senior Programme Manager

Dr Rainbow LEE
Programme Manager

Ms Jan YEUNG
Liaison & Marketing Manager

Dr Kyle CHOW
Assistant Technical Marketing Manager

VISITING RESEARCH FELLOW

Dr Vincent NG (UBDA)

Contact & Subscription

OFFICE
Unit 1212-1213, 12/F, 19W,
Hong Kong Science Park

LABORATORIES
Lab 1:
Room ABC, Unit G02-03, G/F, 16W,
Hong Kong Science Park

Lab 2:
RCC R12, Unit LB-0101, 1/F, 19W,
Hong Kong Science Park

PHONE
(852) 2162 5161

EMAIL
info@cairs.hk

LinkedIN
https://www.linkedin.com/company/cairshk/

FACEBOOK
facebook.com/CAiRSHongKong/

WEBSITE
www.cairs.hk

FOLLOW US TO GET LATEST NEWS!

產品可靠性暨系統安全研發中心

CENTRE FOR ADVANCES IN RELIABILITY AND SAFETY

A Research Centre admitted under *AIR@InnoHK* Cluster