CAiRS at Work

No.3

CAiRS Focus III
Dec 2023

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

STEADY VENTURES AND NEW CHAPTERS

CAiRS
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
UNIVERSITY OF MARYLAND

A YEAR IN FOCUS

ACTIVITIES' HIGHLIGHTS
KNOWLEDGE EXCHANGE
TECHNOLOGY PORTFOLIO

MESSAGE
from CALCE, UMD

PolyU/CAiRS
seminars, lectures and workshops

MESSAGE
from New Director & CEO

Care you, CAiRS

CAiRS Focus III
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MESSAGE FROM

Prof. Wing Tak WONG,

Deputy President and Provost, The Hong Kong Polytechnic University (PolyU)
Chairman, CAiRS Board of Directors

Welcome to the third issue of the CAiRS magazine, CAiRS Focus (III).

The Centre for Advances in Reliability and Safety (CAiRS) is one of three keynote collaborations of the Hong Kong Polytechnic University (PolyU) with renowned international research partners, which operates from the HKSTP, funded by the HKSARG. The establishment of CAiRS is an advanced research collaboration in the field of safety engineering and reliability sciences between PolyU and the University of Maryland (UMD). CAiRS has its objectives in harnessing emerging AI methodologies, data science and innovative technologies, for the improvement of product safety and system reliability across various industrial and commercial applications.

Aside from the research project leaders, notable PolyU and UMD academic staff members with long-established track records in their respective fields, CAiRS also has a diverse pool of high-quality researchers and technical experts from a broad range of disciplines and backgrounds. They contribute to both the impactful research carried out and the effectiveness of innovative safety and reliability methods in real time applications. To date, CAiRS has over 40 industrial collaborators, which indicates the relevance of its outputs in the contributions to ensure a safe smart city at work. These efforts will be showcased in the following sections of this issue of the magazine.

CAiRS has demonstrated the PolyU ethos of "to learn and to apply, for the benefit of mankind" steadily since its beginnings. PolyU looks forward to the growing progress from CAiRS and to witnessing its endeavours in the future. We are confident that CAiRS will continue to thrive and establish itself as a prominent centre for safety and reliability innovations, for applications both big and small, in Hong Kong and beyond.

MESSAGE FROM

Professor Michael G. PECHT,

Director of The Center for Advanced Life Cycle Engineering (CALCE),
University of Maryland (UMD)
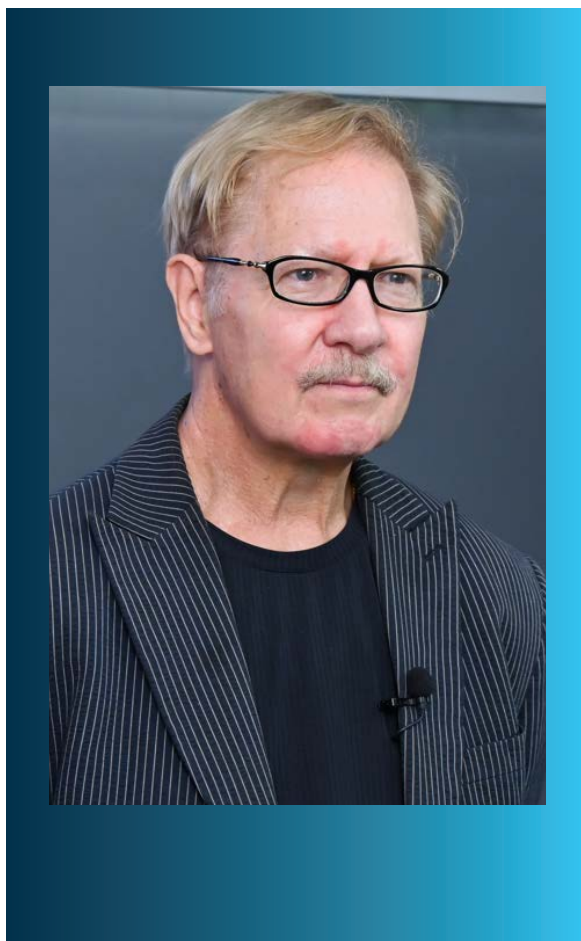
Welcome to the third issue of the CAiRS magazine, CAiRS Focus III.

CAiRS is a notable international advanced research collaboration between the Hong Kong Polytechnic University (PolyU) and the Centre for Advanced Life Cycle Engineering (CALCE), University of Maryland (UMD), funded and supported by the Hong Kong SAR Government. This is the third year of our collaboration and the team at CALCE is delighted at the various milestones made at CAiRS.

The lifting of the Covid-19 travels restrictions saw the return of our regular in-person technical exchanges with the CAiRS team in Hong Kong. The CALCE team is involved with the technical development of CAiRS by contributing to its expertise in fundamental research in AI-based reliability and safety innovations for a wide range of scientific, industrial, and commercial applications. We are also pleased to facilitate the audience in Hong Kong through delivering technical seminars and lectures, attending and hosting keynote forums jointly with CAiRS. We also had the opportunity to visit the collaborators of CAiRS with the Hong Kong team. These technical visits are useful for us to understand better the work undertaken at CAiRS, and in turn how we can further support CAiRS. Our activities and engagement efforts at CAiRS have continued to provide opportunities for technical exchange and global perspectives for the various stakeholders in Hong Kong. You will find further details in the following pages of this issue of the magazine.

CAiRS is not only an innovative technology research centre but also a home for the growing professional dynamics in reliability science and safety engineering in Hong Kong. The team at CALCE is pleased to be part of the progress and we look forward to the next stages of our collaboration with CAiRS.

Brief CV of Prof. Pecht

Prof. Michael G. Pecht (55,000+ citations, 105+ 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 2008, he was awarded the highest reliability honor, the IEEE Reliability Society's Lifetime Achievement Award. In 2010, he received the IEEE Exceptional Technical Achievement Award for his innovations in prognostics and systems health management.

MESSAGE FROM

Professor Kenneth, K. M. LAM,

Centre Director & Chief Executive Officer,
Centre for Advances in Reliability and Safety (CAiRS)

Welcome to the third issue of the CAiRS magazine, CAiRS Focus III. This issue showcases some of our steady ventures and new chapters at CAiRS during 2023. It has been a busy year at CAiRS, with a variety of activities happening all the time.

The Centre for Advances in Reliability and Safety (CAiRS) is one of the 28 recognised and highly innovative R&D centres officially registered under AIR@InnoHK, ITC, HKSARG. CAiRS currently operates at the HKSTP. CAiRS has its remit in the development, application and promotion of the use of AI methodologies and innovative technologies, for the improvement of product safety and system reliability in a diverse range of applications. The creation of CAiRS is also a major long-standing international advanced research collaboration between the Hong Kong Polytechnic University (PolyU) and the University of Maryland (UMD).

In its third year of operation, CAiRS has seen its endeavours going from strength to strength. Our work has led to the publication of 60 research and journal articles, and we have confirmed 17 patents to date, which rightly demonstrates the quality of our technical expertise. CAiRS has continued with our active promotion on matters related to reliability and safety, through both the participation and organisation of technical seminars, professional and corporate events. CAiRS also successfully launched its first spin-off company, ReSaTech Limited, which focuses on the commercial deployment of our developed technologies. We also offered a summer STEM Internship Program, in which we provided learning opportunities for local students to gain applicable innovation and technology work experience. This year also saw the establishment of the IEEE Reliability Society Hong Kong Chapter (IEEE RSHK), with CAiRS as its home. Our activities and engagement efforts have provided platforms for knowledge-in-depth exchange and insightful networking opportunities for our various stakeholders. These will be highlighted in the following sections of this issue of the magazine.

On behalf of CAiRS, I would like to express our sincere appreciation for the unwavering support from our Supporting Organisations, Supporting Companies, Technical and Industrial Collaborators that we have been able to rely on with our work. I would also like to take this opportunity to express my gratitude to Ir Professor Winco K. C. Yung. Prof. Yung had the arduous task of steering CAiRS through its creation and set CAiRS on its course smoothly, under his dedication and leadership in its initial three years of operation. With the torch now passed onto me, I hope to continue with the good work that CAiRS is doing and that I can contribute to its ever more new and exciting chapters to come.

Brief CV of Prof. Lam

Prof. Kenneth K. M. Lam (Senior Member, IEEE) received the Associateship from the Hong Kong Polytechnic University, Hong Kong, in 1986, the M.Sc. degree in communication engineering from the Department of Electrical Engineering, Imperial College, London, U.K., in 1987, and the Ph.D. degree from the Department of Electrical Engineering, University of Sydney, NSW, Australia, in 1996. From 1990 to 1993, he was a Lecturer at the Department of Electronic Engineering, the Hong Kong Polytechnic University, where he was an Assistant Professor with the Department of Electronic and Information Engineering in October 1996. He became an Associate Professor in 1999 and has been a Professor since 2010. His research interests include image and video processing, computer vision, and human face analysis and recognition. Prof. Lam received an Honorable Mention of the Annual Pattern Recognition Society Award for an outstanding contribution to the Pattern Recognition Journal in 2004. In 2008, he also received the Best Paper Award at the International Conference on Neural Networks and Signal Processing. He has been an actively involved member of the organizing committee or program committee of many international conferences and professional bodies. Currently, Prof. Lam is the IEEE SPS VP-Membership, and he is a Member-at-Large of APSIPA. He also serves as a Senior Editorial Board Member for APSIPA Transactions on Signal and Information Processing and an Associate Editor for EURASIP International Journal on Image and Video Processing.

A Year of New Partnerships

28/03/23: A MOU was signed with the Belarusian State University of Informatics and Radioelectronics (BSUIR), with the aim to collaborate and to foster talent exchange in innovative reliability and safety research.

BSUIR is an industry-leading educational and research institution with a focus in information technologies, radio electronics, telecommunications, micro- & nano- electronics. Both CAiRS and BSUIR hope to facilitate talent engagement and enhance research resources. This partnership will be useful for conducting mutually beneficial research activities and other international technical exchanges in the future.

13/06/23: A MOU was signed between CAiRS & MTR. This marks the beginning of a long-term partnership, to promote innovative research exchanges on reliability and safety in mass transportation. The focus is placed on research in three major areas: Anomaly Detection, Knowledge Transfer, Prognostics and Health Management.

Both CAiRS and MTR will utilise our resources and talents who have expertise in innovative technologies, and jointly develop applicable advanced artificial intelligence technology in the future. This collaboration will contribute to the enhancement of the overall reliability and safety of the MTR's operations.

27/09/23: a Collaboration Agreement between The Hong Kong Science and Technology Parks Corporation (HKSTP) and CAiRS was signed. This collaboration aims to provide vital testing and pilot-at-scale capabilities to microelectronics (micro-e) and advanced manufacturing startups.

This HKSTP x CAiRS partnership commits both parties to provide training sessions and consultations for micro-e ventures. The insights from these collaborative engagements will help to unlock significant potential for third-generation semiconductors that can be used in electric vehicles, 5G technology, and for smart manufacturing and transport applications in Hong Kong and the Greater Bay Area.

A Year of Public Engagement

12/04/23 to 15/04/23: CAiRS participated in the inaugural InnoEX 2023 organized by the Hong Kong Government and the Hong Kong Trade Development Council (HKTDC) at Hong Kong Convention and Exhibition Centre, where we showcased our latest advancements in AI-based reliability and safety innovation. CAiRS exhibited under the theme of "Innovations and Smart City".

The event was an excellent opportunity to learn about and understand the current trends and market demands. It was also a platform for us to connect with other professionals in the similar fields, and to have insightful exchanges with fellow technology specialists and innovators from the region and beyond.

A Year of Public Engagement

16/10/23: CAiRS organized and hosted the "Reliability and Prognostics Health Management of Microelectronics Forum" together with HKTDC and HKEIA at the Hong Kong Electronic Fairs. More than 100 guests joined us during the session.

It was a valuable event filled with cutting-edge insights and discussions on the latest advancements in reliability and prognostic health management. The forum brought together industrial specialists and researchers to engage in conversations, with regards to possible enhancements in systems reliability and the impact on the lifespan extension of electronic components.

06/12/23: CAiRS participated in the InnoHK Summit 2023. The event was jointly organized by the Innovation and Technology Commission (ITC) and the Hong Kong Science and Technology Parks Corporation (HKSTPC). This event, under the theme of "From Collaborative Research to Real World Impact", attracted more than 800 world-class academics, scientists, representatives of renowned institutes and industry leaders from the local, regional and global sectors in attendance.

Our Centre Director, Prof. Kenneth Lam, gave a briefing on some of the projects currently undertaken by CAiRS. Prof. Lam's address to the audience highlights the strengths of CAiRS in helping our collaborators to achieve improvements in the reliability and safety of their products and systems. With CAiRS, we can build a reliable and safe city together.

A Year of Technical Knowledge

With the lifting of Covid-19 restrictions by late December 2022, CAiRS gradually returned to providing physical public technical seminars. At the beginning of the year, we still hosted some regular online lectures, provided by our research collaborative partners at the University of Maryland. They are as follows.

Date:	Topic:
04/01/23	In-service assessment of lithium batteries for portable electronics
18/01/23	The Sustainment for Transportation Systems
01/02/23	Towards Interpretable Data-Driven Prognostics
15/02/23	Power electronic component qualification using prognostic tools

Special Mention: A Distinguished Research Seminar

03/02/23: a Distinguished Research Seminar was jointly organised by the Department of Industrial and Systems Engineering (ISE) of the Hong Kong Polytechnic University and CAiRS. The online seminar attracted over 180 participants.

The speaker, Professor Enrico Zio (Department of Energy, Politecnico di Milano, Milan, Italy) shared his extensive experience and knowledge of prognostics and health management for the predictive maintenance of components and systems in various industrial sectors. Prof. Zio highlighted practical challenges and recent developments in advanced techniques and methodologies. It was an enlightening experience for all.

A Year of Technical Knowledge

09/05/23: a CAiRS public seminar titled "Trusts in Product Reliability and Safety" was held. About 100 people from various industries and backgrounds joined the session. Professor Michael G. Pecht (Distinguished Professor and Director for CALCE, University of Maryland) discussed the current state of supply chain complexity and customer practices. More importantly the prevalence of fraud and its impact on customers across all levels were highlighted. Ms. Gabriela Ehrlich (Director of Communications, International Electrotechnical Commission (IEC)) explained the standards that ensure the safety and reliability of the supply chain management in electronic products.

Both topics provide the audience with an opportunity of a comprehensive and global perspective in this technical exchange.

10/08/23: a CAiRS public seminar titled "Strategies for Sustaining Systems Reliability" was held with about 50 people in attendance. Professor Peter Sandborn (CALCE Electronic Products and Systems Center at the University of Maryland) discussed the applications and value in using additive manufactured parts to sustain systems. Dr Siqi Bu (Associate Professor and Associate Head for EEE of the Hong Kong Polytechnic University) focused on the prognostics and health management for induction machines.

Both topics provide the audience with an occasion to understand how these respective methodologies influence the performance of systems in real time.

A Year of Technical Knowledge

On 24/08/23, under the HKSTP x CAiRS collaboration, a public technical seminar & training session was conducted. Around 100 attendees from different industries and backgrounds participated in the event. CAiRS were pleased to host Prof. Michael G. Pecht and Dr. Diganta Das, renowned experts in the field and representatives of our research collaboration partner at the University of Maryland, as our keynote speakers. The theme of the session was Reliability and Safety Risks in Electronics Products and Systems, and multiple aspects were covered within the session.

Visits by VIPs and professional bodies

Over the course of the year, it has been our honour to receive visits from VIPs and professional bodies. These visits allowed us an opportunity to showcase the impactful work that is undertaken at CAiRS.
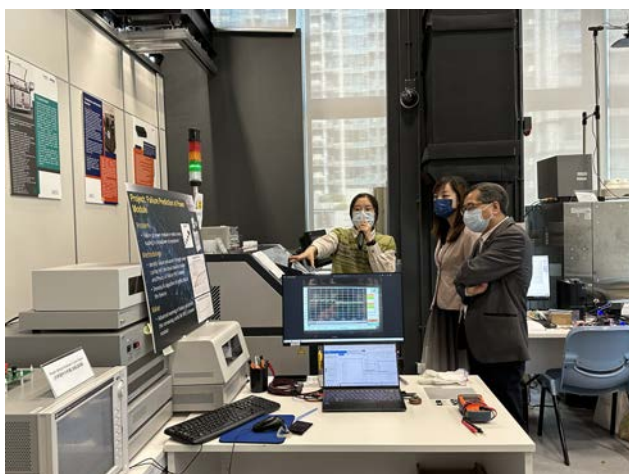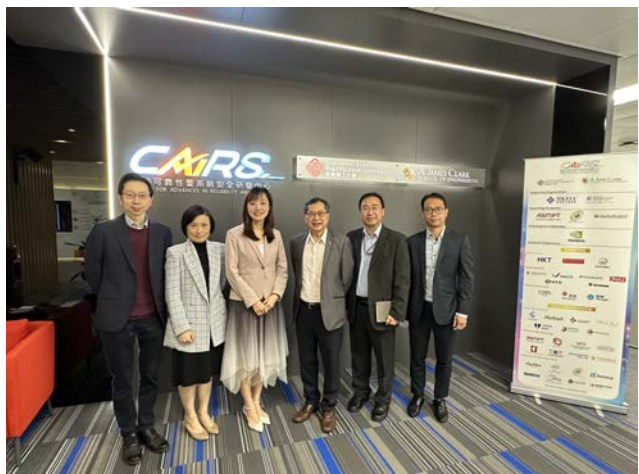
21/01/23: Business Development Team from the Hong Kong Science and Technology Parks Corporation

16/02/23: Dongguan Municipal Government Official Visit
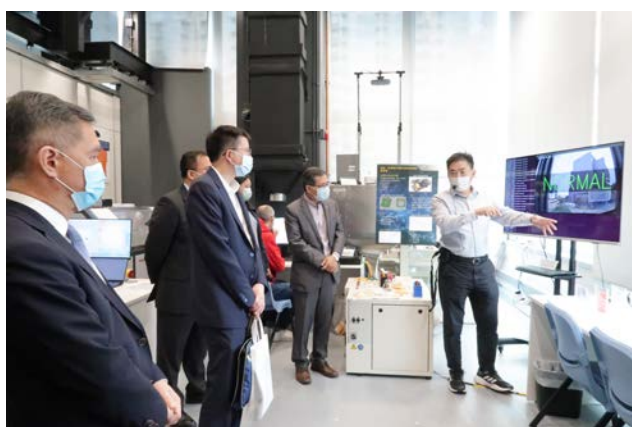
23/02/23: Ms. Lillian Cheong, JP, Under Secretary for Innovation, Technology and Industry

Visits by VIPs and professional bodies

24/02/23: PolyU VPRI Office – Ir Prof. Christopher Chao and team

07/06/23: PolyU Council and Court Secretariat

26/06/23: Institution of Engineering and Technology (IET) HQ, Prof. Bob Cryan and team, and 07/09/23: IET Hong Kong representatives

Corporate and Collaborators' Visits

It has also been our pleasure to host corporate visits for collaborators and industrial stakeholders during the year. Insightful technical exchanges and productive discussions on potential collaboration opportunities were made.

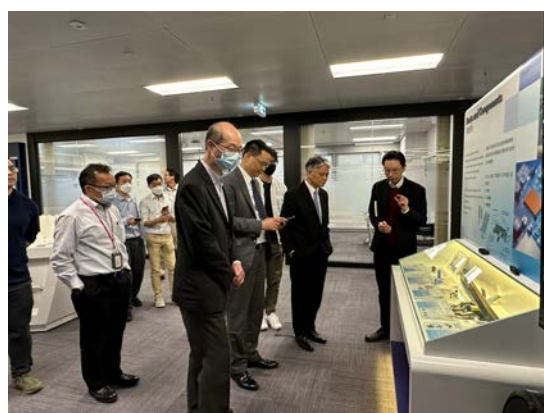| 01/02/23: Robocore Technology Limited	28/02/2023: Yau Lee Construction Co., Ltd.

03/03/23: Intertek Testing Services HK Limited	24/03/23: HK Electric

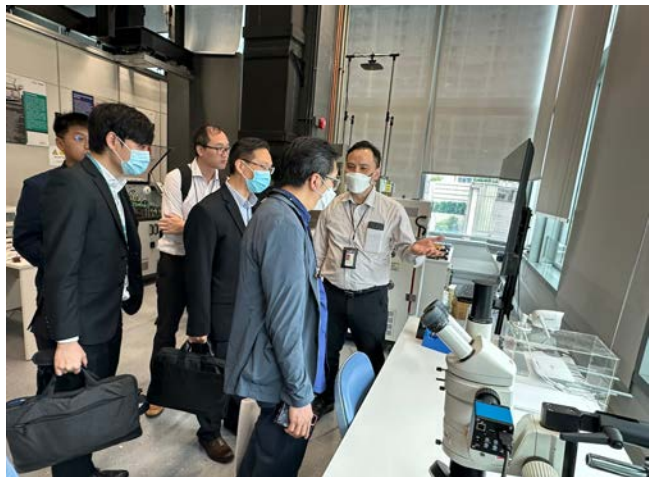| 27/04/23: Jecko Elevators Limited	17/05/23: Sun East Group Limited

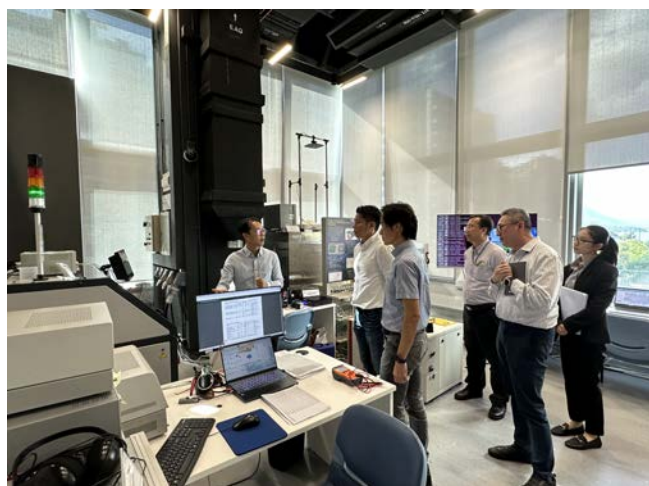# Corporate and Collaborators' Visits

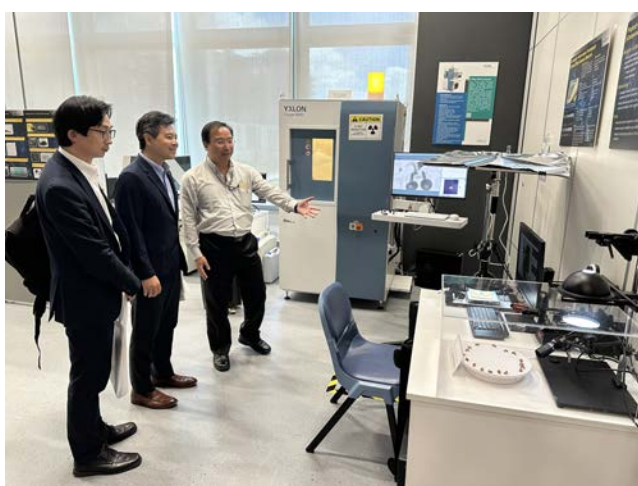19/05/23: CLP Power Hong Kong Limited

09/06/2023: Synovate Technologies (Shenzhen) Co., Ltd.

20/06/23: Sanfield Construction Innovations Limited

11/07/23: WKK Distribution Ltd.

16/08/23: WeEn Semiconductors Co. Ltd.

30/08/23: Mei Ah Entertainment Group Ltd.

Establishment of the IEEE Reliability Society Hong Kong Chapter, IEEE RSHK

The official inauguration of IEEE Reliability Society, Hong Kong Chapter (IEEE RSHK) took place on 27/09/23, in conjunction with the signing of a Collaboration Agreement between HKSTP x CAiRS. The occasion was attended by over 100 guests from government, industry, and academia. The event also featured a round-table forum, keynote speeches and industry sharing sessions from renowned experts and industry partners in reliability, prognostics, and safety.

The IEEE RSHK is a dynamic professional organization dedicated to the technological advancement and promotion of reliability and safety in Hong Kong. As a local chapter of the global IEEE Reliability Society, it serves as a platform for professionals, researchers, and students to collaborate, exchange knowledge, and enhance their skills in the field of reliability. The IEEE RSHK also aims to provide a global professional perspective for the local and regional audience.

The IEEE RSHK aims to develop and disseminate information with regards to reliability best practices such as testing methodologies, compliance and certification procedures, system reliability, and product reliability. It will also be a leading forum to discuss technological issues related to reliability in Hong Kong, including but not limited to issues, standards, and jobs. It will provide members with a professional platform to share experiences, learn and develop together. By fostering collaboration and knowledge exchange, the IEEE RSHK hopes to play a vital role in the advancement of safety and reliability engineering in Hong Kong. CAiRS is delighted to provide full support for its activities.
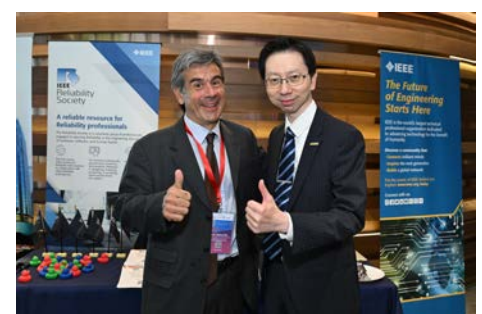
ReSaTech Limited is the official spin-off company set up in association with CAiRS. It was independently registered in Hong Kong in November 2022. ReSaTech was awarded HKD500,000 under the HKSARG Technology Start-up Support Scheme for Universities (TSSSU) Fund for the year 2023-2024.

ReSaTech develops customized AI deep technologies for predictive maintenance applications, where the required technical solutions also cover industrial anomaly detection, diagnostics, and prognostics. Anomaly detection and diagnostics respectively serve as data acquisition and health indexing for prognostics.


Its integrated AI knowledge models are developed and extracted from real data within the successful cases undertaken by CAiRS. Its advantage is having well-optimized and validated solutions under these broad scope industrial testbeds, and hence will be more bespoke and applicable in comparison with the off-the-shelf solutions currently available in the market. ReSaTech solutions aim to improve product reliability and system safety with primary applications in transportation, public utilities, manufacturing and construction/building industries in Hong Kong.

Laboratory Assets

At CAiRS, we have our own laboratory equipment and physical testing assets which support the data acquisition required for various aspects of our work. Please refer to our website for further technical details.

High Performance Computing
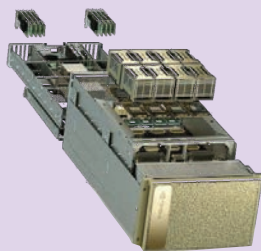
The NVIDIA DGX^{TM} A100 supercomputer

Temperature and Environment Testing

High Temperature Oven (with Temperature Cycling)

Temperature and Humidity Chamber (with Temperature Cycling)

Highly Accelerated Stress Test (HAST) Chamber

Thermal Shock Chamber

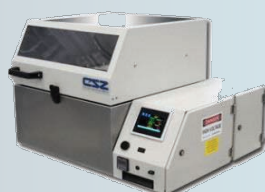## Life Cycle Assessment

Power Tester

Interrogator

Battery Charge/Discharge Testing System
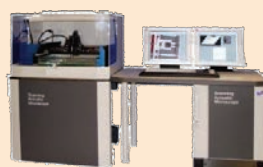
Power Device Analyzer Curve Tracer

Benchtop Vibration Table

Shock Impact Tester

Failure Analysis

Scanning Acoustic Microscope

X-Ray Microscopy (2D & 3D)

Electrodynamic Tester

Nano-indenter

X-Ray Fluorescence (XRF) Spectrometer

Technology Portfolio

By the end of the year, a total of 17 patents, both applied for and granted, is confirmed for the various technologies developed at CAiRS. The following pages showcase our developed technologies associated with industrial and commercial applications. Some of these will feature in the International Exhibition of Inventions Geneva 2024.

Cable Prognosis: AI-Driven Predictive Health Index System and Remaining Useful Life Prediction for Underground Cables
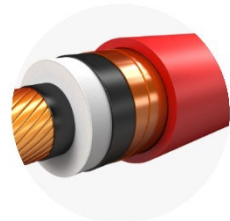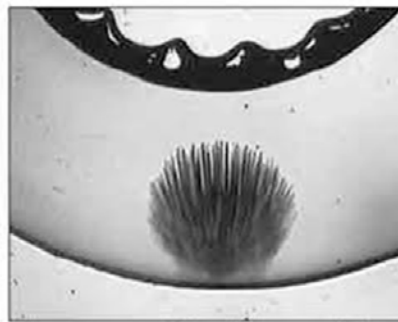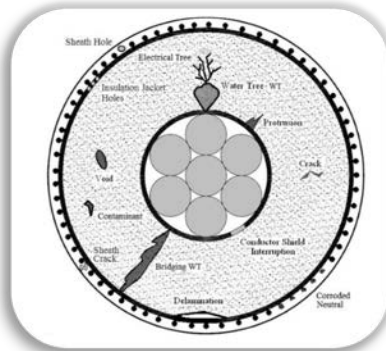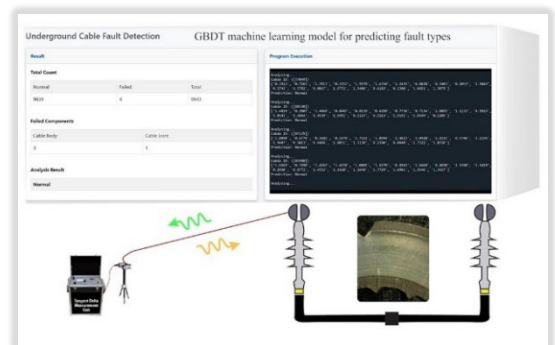

The Problem:
- Underground power supply cables are susceptible to compromised performance due to various defects.
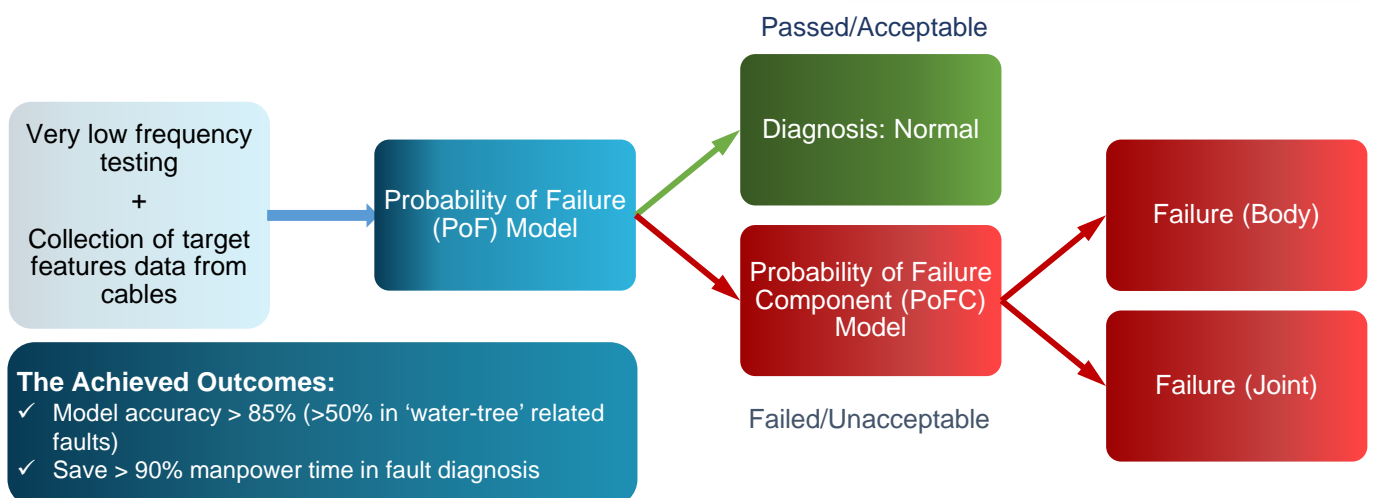
The Desired Mitigation:
- To reliably provide
- Health diagnosis of underground power cables,
- Advanced warning of anomalies,
- Prevention of power outage and related incidents, and,
- Optimization of scheduled maintenance (i.e., savings in manpower).

Solution Output:
Provision of precise diagnostic and health monitoring parameters.

Tailored Solution at CAiRS

Very low frequency testing
+
Collection of target features data from cables

→ Probability of Failure (PoF) Model

Passed/Acceptable → Diagnosis: Normal

Failed/Unacceptable → Probability of Failure Component (PoFC) Model → Failure (Body), Failure (Joint)

The Achieved Outcomes:
- ✓ Model accuracy > 85% (>50% in 'water-tree' related faults)
- ✓ Save > 90% manpower time in fault diagnosis

Patent details
Title: A Health Index System and Method of Predicting Health Condition in Underground Cables.
Registered region and date: Hong Kong, 03/03/23
Patent No: HK30081188

Technology Portfolio

VehicleGuardian: AI-Enhanced Online Health Monitoring and Remaining Useful Life Prediction for Vehicle Engine Cooling Systems
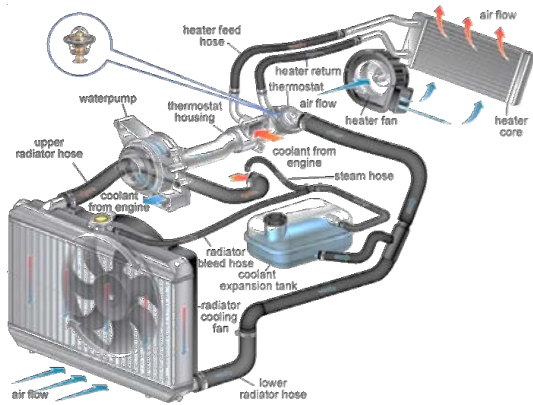
The Problem:
- Vehicle overheating is one of the common causes for breakdowns whilst in traffic.
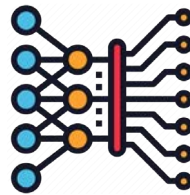- Lack of timely early prediction/indication of likely problems.

The Desired Mitigation:
Provide an early warning system.
Provide diagnostics on anomalies.

Solution Features:
- ✓ Ensemble methods in machine learning for anomaly detection.
- ✓ Machine learning-based approach for Remaining Useful Life (RUL) prediction.

Tailored Solution at CAiRS

Data Inputs: Cooling Performance Indicators
- Coolant Temperature
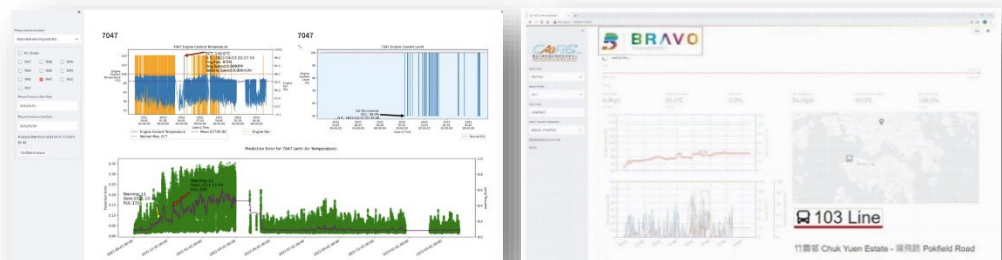- Fuel Rate
- Air Temperature
- Fan Speed

AI Methods: PoF + Ensemble of Multiple DDM
- MLP-AE,
- OC-SVM,
- OC-ELM,
- Isolation Forest

Health index classification for RUL prediction

Solution Output:
Auto warning system to inform engineers about the vehicle's health status

The Achieved Outcomes:
Reliable detection of anomalies (case studies had been successfully run on 10 buses in current service).
Enhanced management of maintenance schedules and required manpower.

Patent details
Title: System and Method Of Anomaly Detection Of Thermostat in a Vehicle.
Registered region and date: PRC
Patent No: 202211063009.8

LithioGuardian: Online Lithium-ion Battery Health Monitoring System with FBG Sensors

The Problem:
- Li-ion cells display noticeable physical deformation either due to defects or towards end of useful life. In particular, the cells swell and expand in size.
- The extent of this deformation, by the time it is discovered, is often variable.
- Damage to the components in proximity of the cells and perhaps even the whole device, may not often be discovered in time due to the occurrences.
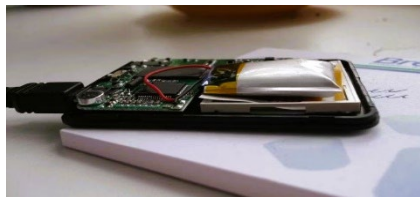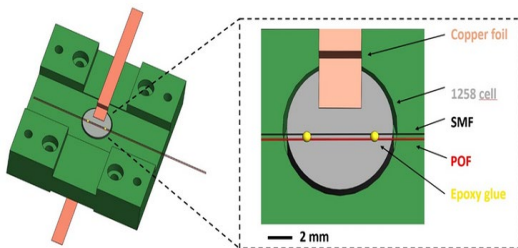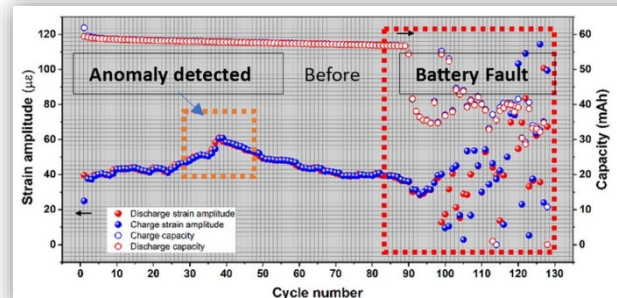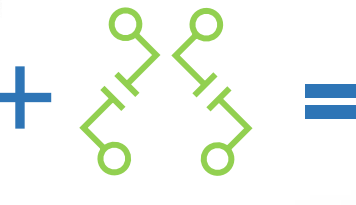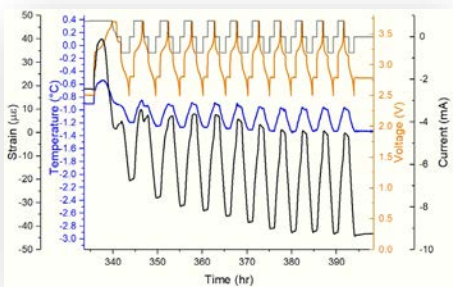
The Desired Mitigation:
Provide an early indication and detection of battery and cell defects/abnormality.
Provide a prediction of remaining useful life and/or other critical parameters.

Tailored Solution at CAiRS

Stage 1a: Raw Data Acquisition – Mount Fibre Bragg Grating (FBG) sensors (i.e., sensory 'canary') on batteries.

Stage 1b: Raw Data Acquisition – Measure the strain and temperature associated with the electrochemical reactions (e.g., strain and temperature)

Stage 2:
Decoupling of raw optical signals from the FBG sensors into physical parameters. Provide health indicators.

Solution Output:
Consistent anomaly detection and prediction of remaining useful life.
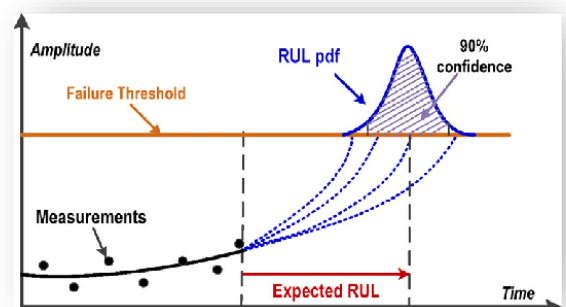
The Achieved Outcomes:
Anomalies or the end-of-life of batteries can be predicted early and accurately before catastrophic failure occurs.

Patent details
Title: A System and Method to Monitor Lithium-ion Battery for Degradation Estimation and Fault Detection.
Registered region and date: Hong Kong, 01/08/23
Patent No: HK30088739

RailSwinX: Enhanced Rail Track Defect Detection Through Cutting-Edge AI Technology

Typical Onboard Rail Inspection System (ORIS) in use

The Problem:
- Limitation of conducting inspections solely during non-traffic hours.
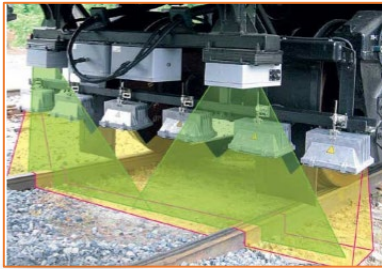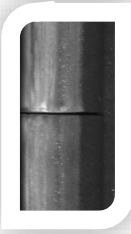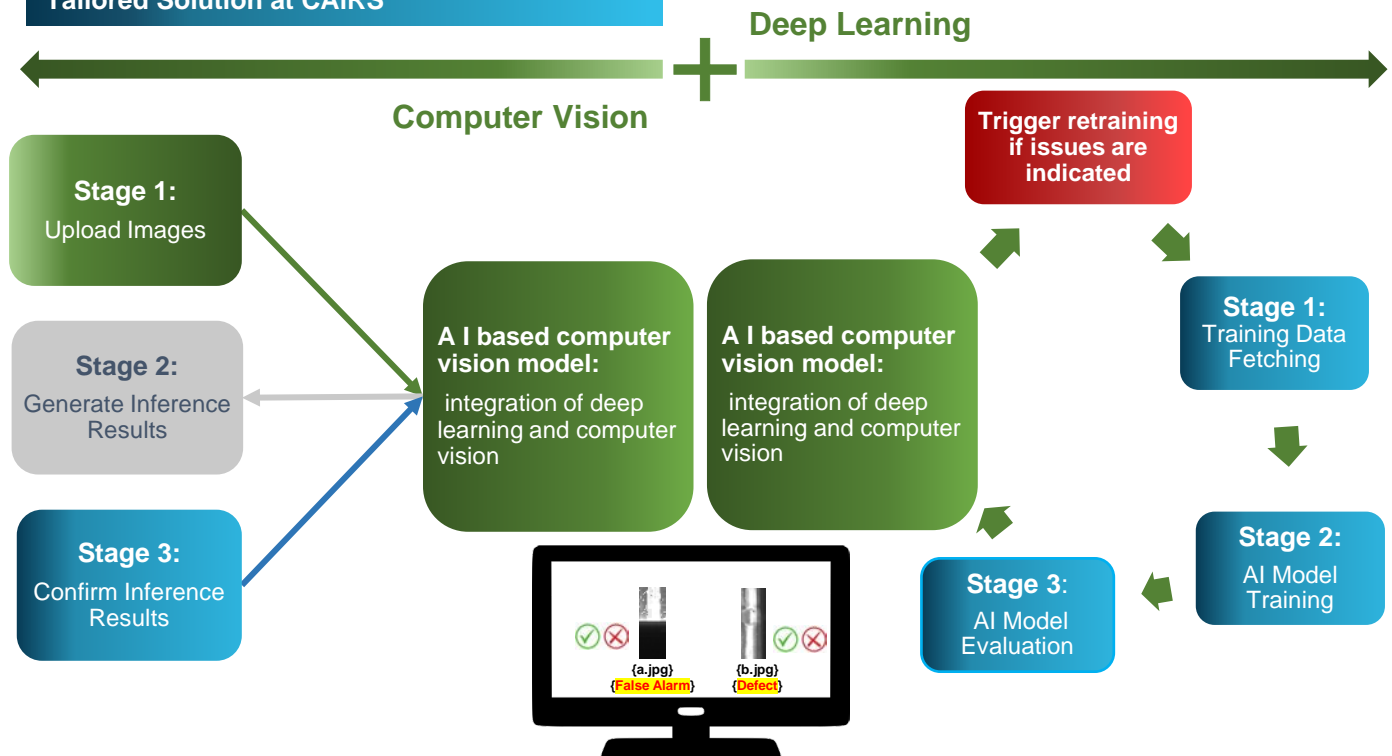- High false alarm rate in the existing Onboard Rail Inspection System (ORIS).

Collected false alarm (left) and real time defect (right) rail track images obtained by a railway operator.

The Desired Mitigation:
- Reduce false alarms and detect defects with a high accuracy rate.
- Automatic inspection & maintenance prioritization based on the defect severity.
- Enhance safety and service reliability.

Tailored Solution at CAiRS

Computer Vision + **Deep Learning**

Stage 1: Upload Images

Stage 2: Generate Inference Results

Stage 3: Confirm Inference Results

A I based computer vision model: integration of deep learning and computer vision

A I based computer vision model: integration of deep learning and computer vision

Trigger retraining if issues are indicated

Stage 1: Training Data Fetching

Stage 2: AI Model Training

Stage 3: AI Model Evaluation

{a.jpg} {False Alarm}   {b.jpg} {Defect}

Synthetic Rail Track Image Generation

Real Defect

Real False Alarm

Synthetic Defect

Synthetic False Alarm

The Achieved Outcomes:
- Modelled system false alarm rate: >8x improvement in accuracy
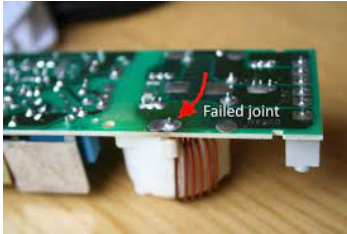- Precision is at approximately 99.4%

Patent details

Title: Improving Rail Tracks Defect Classification Based on a Cascade Swin-Transformer Model.

Registered region and date: Hong Kong

Patent No: 30096108 A

SolderSense: A Novel AI Failure Prediction System for PCB Solder Joints Using Thermal Imaging Analytics

The Problem:
Lack of early detection of solder joint failure mechanisms on the production line of printed circuit boards (PCB). Quality control in PCB production and assembly is often difficult.
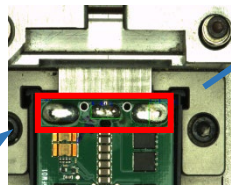
The Desired Mitigation:
- Provide an automatic soldering defect identification and diagnosis
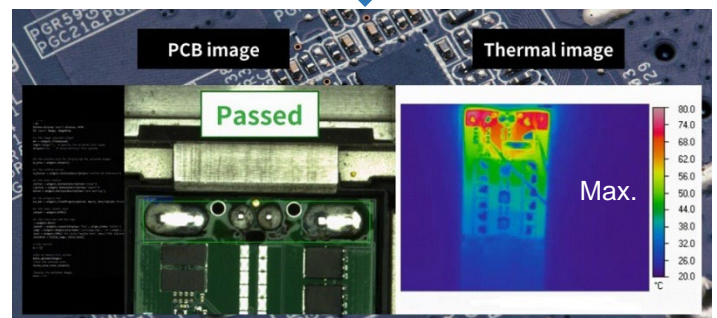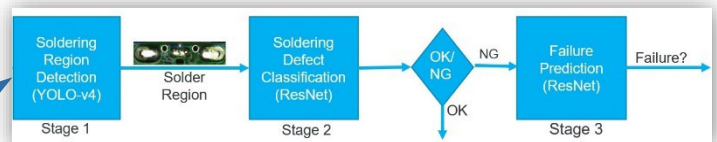- Reduce rejects and predict reliability of PCB in the assembly stage.

Tailored Solution at CAiRS

Image Capture System

PCB sample image with focus on solder region

Stage 1	Stage 2	Stage 3
Soldering Region Detection (YOLO-v4) → Solder Region	Soldering Defect Classification (ResNet) → OK/NG	NG → Failure Prediction (ResNet) → Failure?

PCB image — Passed | Thermal image — Max.

Solution Features:
✓ AI based computer vision model – provision of a non-destructive monitoring system, based on a thermal imaging camera for the detection of PCB soldering failure mechanisms under high current usage.

Solution Output:
AI based solder joint failure prediction model.

Solder defect type	RGB	Thermal	Failure (>125°C)
Ok			N
Pseudo joint			Y
Copper pad exposed			Y
Sharp edge			Y
Less tin			Y
Too much tin			Y
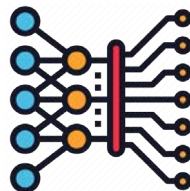
The Achieved Outcomes:
- Accuracy: > 85%
- Reduced device malfunctions by more than 25% (due to soldering quality issues)

Patent details

Title: AI-Based Failure Mechanism Prediction System and Method for PCB Solder Joints.

Registered region and date: Hong Kong, 08/11/23

Patent No: HK30094933

22

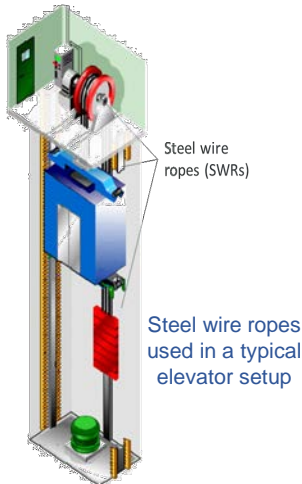**WireInspect:** Anomaly Detection System for Elevator Steel Wire Ropes Using Deep Learning Models

Steel wire ropes (SWRs)

Steel wire ropes used in a typical elevator setup

The Problem:
- Existing maintenance and inspection work for steel wire ropes are typically dependent on manual inspection via visual checks and manual measurements.
- Enhanced and timely fault detection is not easily arranged.

The Desired Mitigation:
- Provide an advanced solution which better helps to investigate the health, degradation, and aging mechanisms of steel wire rope (SWR) used in lift systems.
- Achieve functional safety improvement.

Tailored Solution at CAiRS

Stage 2: Fusion of Techniques –
Data Processing, Proof of Concept (PoC) and A I Models
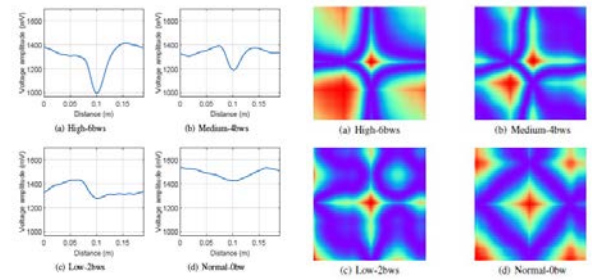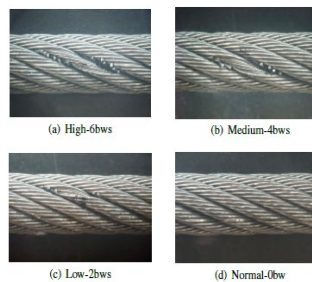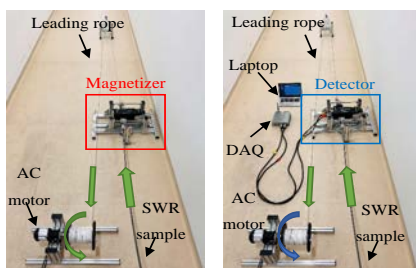
Stage 1: Magnetic Flux Leakage – Physical Experiment and Raw Data Acquisition
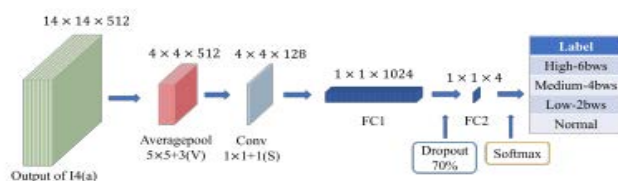
Stage 2: Fusion of Techniques –
Data Processing, Proof of Concept (PoC) and A I Models
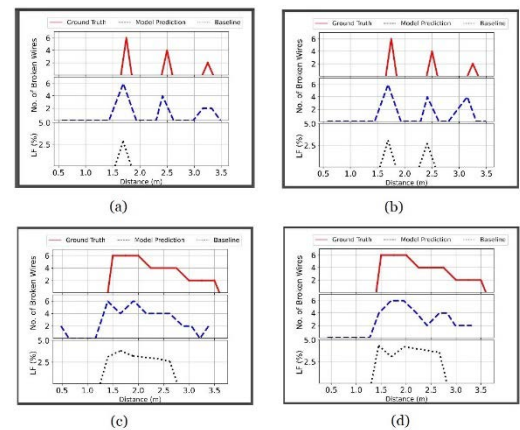
The Achieved Outcomes:
✓ Model accuracy is at around 91%

Solution Output:
Application with defect detection mechanisms

Patent details
Title: System and Method of Data-Driven Deep Learning Models for Detecting Anomalies in a Steel Wire Rope.
Registered region and date: Hong Kong, 08/06/23
Patent No: HK30088200

Title: System and Method to Detect Anomalies in a Steel Wire Rope (SWR) of an Elevator Based on Changes in Raw Magnetic Flux Leakage (MFL) Data
Registered region and date: Hong Kong, 01/08/23
Patent No: HK30089194

MotorGuard: Automated Motor Health Monitoring and Failure Diagnosis with a Rule-based Expert Inference System

The Problem:
- Flue gas desulfurization (FGD) system excludes sulphide generated during the coal combustion in the power industry.
- The anomalies of FGD motor will lead to fail of booster fan, lead to direct emission of pollutants to air.

The Desired Mitigation:
- Perform diagnostics of FGD motor.
- Predict remaining useful life of FGD motor through suitable data driven AI modelling and training.
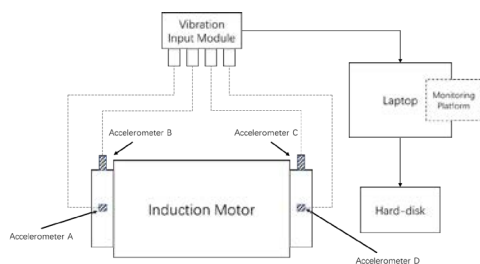- Provide a motor health monitoring system which,
  - Show motor operation status,
  - Detect, diagnose, and give warnings, and,
  - Classify anomalies.

Tailored Solution at CAiRS

Stage 1: Data Acquisition System – Real-time vibration data collection

Stage 2: Remaining Useful Life (RUL) Prediction – Computational Simulation, AI Modelling and Training
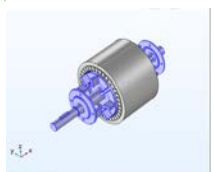
Motor shaft simulation using COMSOL
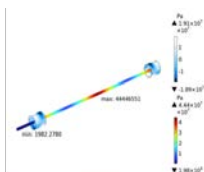
(AI training result: Health Indicator vs Lifetime)
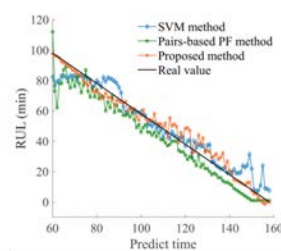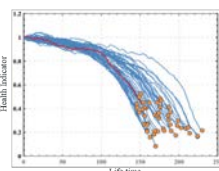
Method	Prediction-RMSE
SVM	45.597
Pair-based-PF	38.748
Proposed-method	6.759

The Achieved Outcomes:
- Model accuracy ≥ 90%
- (F1-score).
- Fault diagnostic times reduced by over 80%.
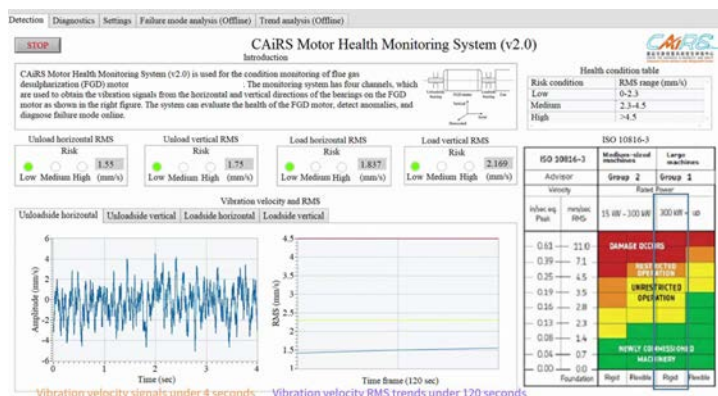
Solution Output:
Provision of a motor health monitoring system with user interface.

Patent details
Title: System and Method for Condition Monitoring of an Induction Motor.
Registered region and date: Hong Kong, 18/10/23
Patent No: HK30094379

ManufacturoVision: Real-time Defect Detection and Classification System using Deep Learning for Multi-Material Components

The Problem:
- Components used in anti-lock brake systems (ABS) need to be precisely manufactured during the injection molding process.
- Defects in the ABS-related components need to be detected timely and accurately.

Normal | Break | Shrinkage | Burn mark | Missing Pin

The Desired Mitigation:
- Perform fast and accurate real-time defect detection.
- Enhance the quality of ABS-related components.
- Increase reliability and safety in the brake system.

Tailored Solution at CAiRS
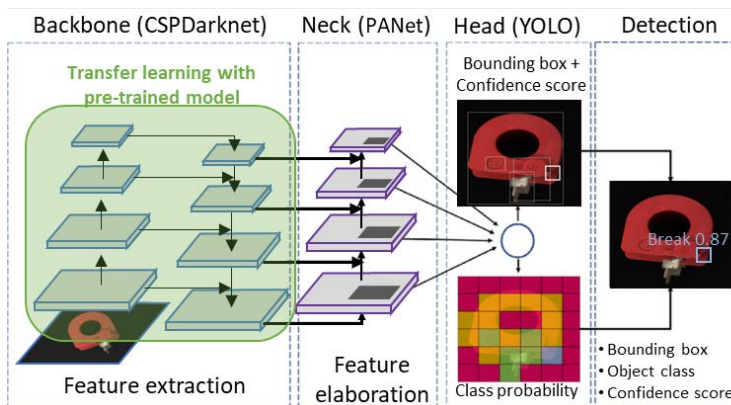
Solution Features:
- ✓ Data augmentation by fusion approaches.
- ✓ Environment and camera adjustment.
- ✓ Computational approach.
- ✓ Object detection model by YOLOv5.
- ✓ Real-time defect detection by transfer learning with YOLOv5.

Solution Output:
- Live production monitoring
  - Real-time, dynamic inference 'observation' window.
  - Real-time user-interactive system, interface and dashboard.

The Achieved Outcomes:
- ✓ Model accuracy is at 98.6%
- ✓ Detection rate can support over 0.34 million product samples per day
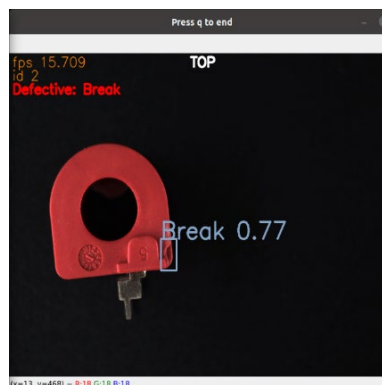
Patent details
Title: A Defect Detection and Localization Method and System with Fusion Data Augmentation for Plastic Injection Molding Product.
Registered region and date: Hong Kong, 28/02/23
Patent No: HK30080291

Title: A Deep Learning Model of Defect Detection Method and System for Plastic Injection Molding Products.
Registered region and date: Hong Kong, 06/04/23
Patent No: HK30082979

ClearLens: Cutting-Edge Camera Tampering and Anomaly Detection System for Video Surveillance

Problems:
- Surveillance cameras can give low-quality videos/images due to ageing, intruder attack, physical disturbances on lenses, etc.
- Smart systems using these low-quality videos may make wrong decisions and lead to serious consequences

Objectives:
- Develop an AI-based system that monitors surveillance camera video in real-time
- Evaluate the quality of the video by detecting the common anomalies including haze, defocus, dirt, and spray paint blur

Normal

Haze

Defocus

Dirt

Spray paint blur

System Architecture

Cam 1: Normal
Cam 2: Dirt
Cam 3: Normal
:

Proposed deep learning AI model

Difficulty: Highly imbalanced training data
- Imbalance in quantity
- Surveillance images with defects are difficult to find – significantly affects the accuracy of their detection
- Imbalance in data distribution
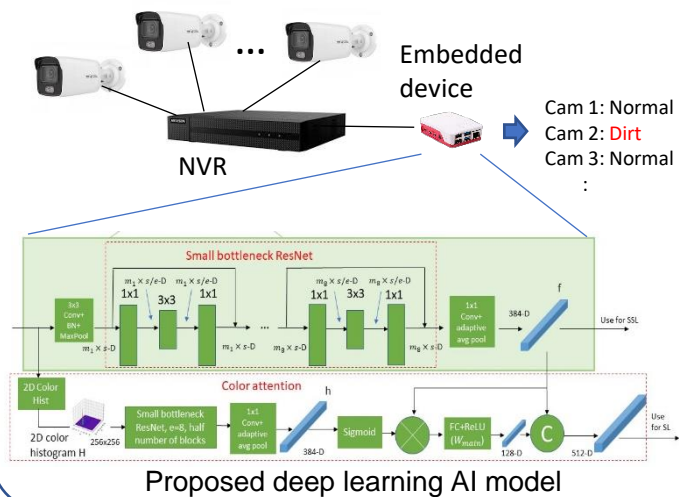- Some image classes are similar while some classes are significantly different – leads to overfitting in training

Solutions:

Data level:
- Develop two new dirt and spray paint blur image synthesizers to generate anomalous surveillance images to balance the training dataset

Algorithm level:
- Develop a self-supervised attention-based deep residual model Fully utilizes the special features of anomalous images to tackle the imbalanced data distribution problem
- Design a small bottleneck ResNet structure to simplify the model complexity for the implementation with embedded devices

Results:
Develop an image dataset of 15,000 images
- Training set contains 4 anomalous image classes with same number of image samples
- Synthesized images closely resemble the real ones

Develop a low-cost (<US$150) surveillance camera monitoring system

Real-time scanning a 30-camera surveillance system in about 30 sec in the background without affecting the normal operation of the system

Achieve an accuracy of over 90% on detecting four common anomalies in surveillance videos

Patent:
- Title: System and Method for Spray Paint Image Synthesis in Surveillance Camera Anomaly Detection.
- Registered region and date: Hong Kong, 02/12/22
- Patent No: HK30076502

- Title: System and Method for Surveillance Camera Anomaly Detection.
- Registered region and date: PRC
- Patent No: 202211032284.3

Car 1 (3613) | Car 2 (1613) | Car 3 (2613) | Car 4 (2614) | Car 5 (1614) | Car 6 (3614)
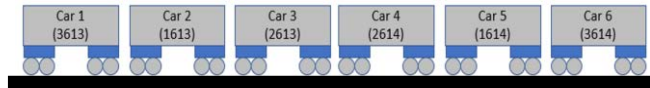
RailScan: AI Train Rail Anomaly Detection & Remaining Useful Life Modeling

Problems:
- Railway track is critical in transportation safety as it can lead to train derailment.
- Track anomaly detection & Remaining Useful Life (RUL) modeling are essential for diagnostics and prognostic health management.

Objectives:
- Determine the railway track defective location using AI Data Driven Methodologies (DDM)
- Build railway track degradation model & estimate the Remaining Useful Life (RUL)

Generic Degradation Index and RUL model
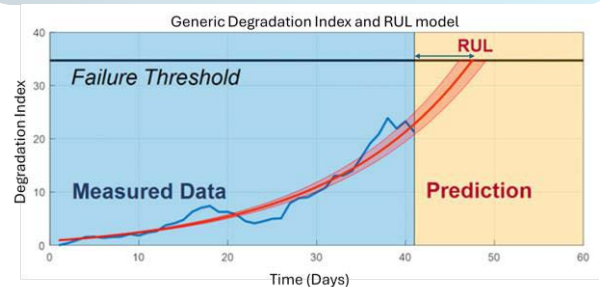
Methods:
- Anomaly Detection: Track vibration data/Fast Fourier Transform/ResNet
- RUL: Track vibration data/Functional Data Analysis /Auto-Encoder/Degradation (Health) Index

Results:
- ✓ Accurately predict probability of track anomaly (Accuracy: ~85%)
- ✓ Accurately predict track RUL (Root Mean Square (RMS) Error <10%)

Scale Down Model (Left) & Train Rail Axle Box Vibration Data (Right)

Anomaly Detection

Step 1 Train Rail Vibration Data → Step 2 Digital Signal Processing → Step 3 Unsupervised Outlier Detection for Data Label → Step 4 Supervised Model Training → Step 5 Rail Maintenance

RUL Model

Step 1 Train Rail Vibration Data Frames → Step 2 Data Frame Transforms to Spatial Temporal Functions → Step 3 Auto-Encoder Latent Space Classifier → Step 4 Impulsive/Non-Impulsive Clustering → Step 5 Train Rail Degradation (Health) Index

Non-impulsive | Impulsive

Degradation Assessment (FDA) | Anomaly Phenotyping (HCTSA)

FDA: Functional Data Analysis
HCTSA: Highly Comparative Time Series Analysis

Train Rail Degradation Index

$$D(t) = \frac{B_o}{B_o(t)} \, e^{\left(\frac{A(t)}{A_o}\right)}$$

A(t) = Sum of Impulse(s) Detection (time t< T)
B(t) = Correlation at time (t)

Degradation Index Over Time

RoboGuide (I): Intelligent Collision Avoidance Prediction

Problem:
- When a mobile robot moves with autonomous navigation, it is difficult to predict the direction, velocity, and collision area of dynamic obstacles, which increases the collision risk

Objective:
- Apply object tracking methodology on sensor data (LiDAR/RGB/RGB depth) to create a local costmap for collision avoidance tracking of dynamic object(s)
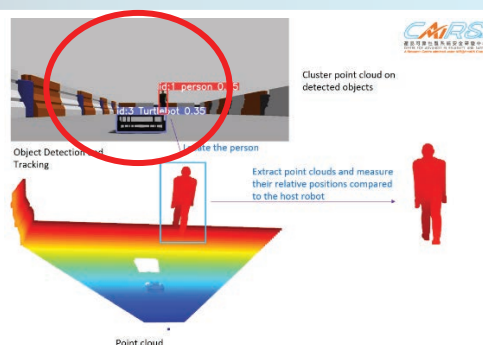
Methods:
- Real-time detection and tracking of moving obstacles.
- Record/predict the position and speed of moving obstacles, with short-term updates
- Build an improved local cost map that includes areas occupied by the moving obstacles

Results:
- Accurately track moving object(s) and predict probability of collision
- Accuracy: >90%
- with local cost map
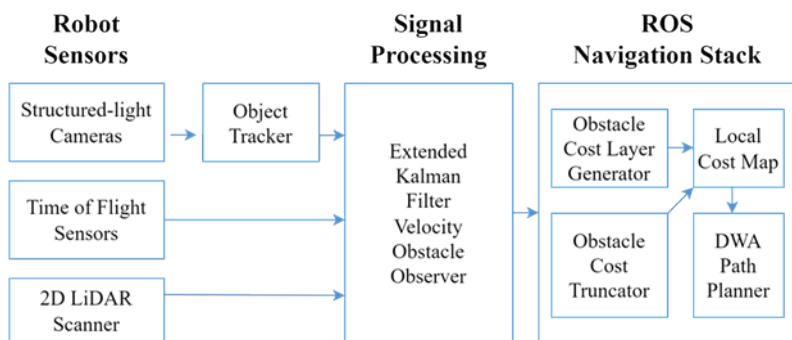
Copyright:
Title: Dynamic Obstacle Detection, Tracking, and Collision Prediction Software
Registration and date: China Copyright Protection Center , 23/01/31
Application No: 2024R11S0232175

Technology Portfolio

RoboGuide (II): Smart Digital Twin Hazardous Object Detection

Problems:
- Unlawful or hazardous activity in large private venue is difficult and/or laborious to be detected
- It is impossible or difficult to collect significant number of images of hazardous situations for AI model training

Objectives:
- Equip patrolling robot with hazardous object detection capability using AI transfer learning.
- Create synthetic images by simulation to solve the insufficient/no image problem.

Methods:
- Apply hazardous object detection with transfer learning on YOLO model
- Simulate significant number of hazardous images data (fire/knife/gun…etc) by Nvidia Omniverse for YOLO training

Results:
- Accurately predict hazardous objects in hospital environment on robot Temi
- Precision: ~ 90%

Synthetic images
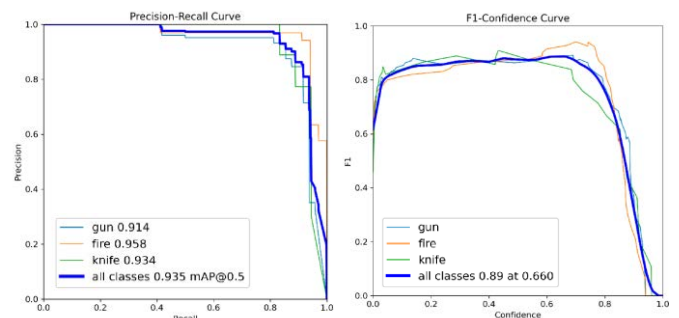
	Instances	Precision	Recall	mAP50	mAP50-90
All	122	0.893	0.806	0.886	0.642
Gun	39	0.917	0.855	0.929	0.741
Fire	51	0.8	0.783	0.851	0.504
Knife	32	0.961	0.78	0.878	0.682

Precision-Recall Curve
- gun 0.914
- fire 0.958
- knife 0.934
- all classes 0.935 mAP@0.5

F1-Confidence Curve
- gun
- fire
- knife
- all classes 0.89 at 0.660

Technology Portfolio

In Numbers – Patents of CAiRS

3 — Anomaly Detection and Syndromic Surveillances

Innovative Diagnostics for Health Management — **3**

3 — Prognostics for Remaining Useful Life Assessment

Safety Assurance: Improve Functional Safety — **6**

2 — Data Analytics Platform for Reliability

A total of **17** Patents across **5** Research Programs

In Numbers – Publications of CAiRS

60 Research and Journal Publications

- IEEE Transactions, IEEE Access… (and many other titles)
- Sensors, Materials & Design, Mathematics, Batteries, Nanomaterials, Electronics, Optics Express…
- Reliability Engineering and System Safety, Industrial Management and Data Systems…
- Electrochimica Acta, Frontiers in Chemical Engineering, Journal of the Electrochemical Society, …
- Energies, Frontier in Energy Research, Journal of Power Sources, Renewable and Sustainable Energy Reviews…
- Expert Systems with Applications, Advanced Intelligent Systems, Knowledge-Based Systems…
- Transactions on Hong Kong Institution of Engineers, Ain Shams Engineering Journal…

Corporate Information

Feedback and Support – Letters of Appreciation

We are delighted to have received letters of appreciation from the following collaborators this year. Feedback from our collaborators is a recognition and confirmation that our work is of value and use to those we serve.

港燈 HK Electric	ASMPT	Citybus 城巴
12/06/23	15/06/23	06/11/23
GPB GP Batteries International Limited 金山電池國際有限公司	blue pin	煤氣 Towngas
07/11/23	08/11/23	30/12/23

Feedback and Support – Reported in Media

We are also pleased to have our work with one of the collaborators, HK Electric, reported in the local media this year.

智慧城市｜港燈藉 AI 及大數據監察電網 電纜異常事件激減 4 成
(摘自星島日報 (A8) 及 星島頭條網 Online News, 27/12/2023)

"…港燈去年與香港理工大學創立的產品可靠性暨系統安全研發中心（CAiRS）合作，開發一款 AI 人工智能軟件，新模型結合港燈過往 10 多年的檢測大數據，可預測是電纜線身或是接駁箱出現異常的風險較大。"

"…港燈今年初試行 AI 模型，能量化電纜各部件異常機率，為一條電纜不同位置分別評分，可大幅提升檢查電纜的準確度及效率。現時精準度達 7 成，相信未來有更多數據投入作分析，可以更快更準，守護城市血管的健康。"

Corporate Information
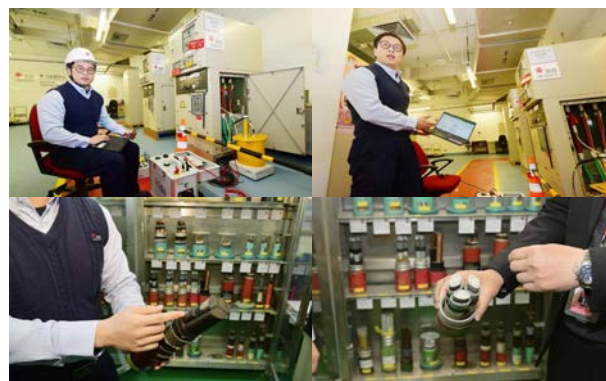
People of CAiRS – Research Project Leaders

The technical expertise and innovative strengths of CAiRS come from the dedication and support of renown and highly recognized academics, professionals and experts in their research and industrial domains.

Prof. Kenneth LAM,
Director and CEO of CAiRS

Prof. Steven BOLES,
Adjunct Professor (EEE)

Dr. Siqi BU,
Associate Professor and Associate Head (EEE)

Dr. Yui-Lam CHAN,
Associate Professor (EEE)

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Research Project Leaders from PolyU

Prof. Edward CHUNG,
Professor (EEE)

Dr. Nick CHUNG,
Associate Professor (ISE) & Associate Head (IGDS)
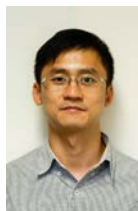
Prof. Haibo HU,
Professor (EEE)

Prof. Francis LAU,
Professor (EEE)

Dr. Carman LEE,
Associate Professor (ISE)

Ir Dr. Daniel LUN,
Associate Professor & Associate Head (EEE)

Dr. Ka Hong LOO
Associate Professor (EEE) & Assistant Dean (FENG)

Dr. Xiaoge ZHANG,
Assistant Professor (ISE)

Ir Prof. Winco YUNG
Senior Consultant

Prof. Michael G. PECHT,
Head of Research Programs

A. JAMES CLARK
SCHOOL OF ENGINEERING

Research Project Leaders from UMD

Dr. Michael AZARIAN

Dr. Diganta DAS

Prof. Siddhartha DAS

Prof. Abhijit DASGUPTA

Dr. Namkyoung LEE

Dr. Michael OSTERMAN

Prof. Peter SANDBORN

Corporate Information

People of CAiRS - Centre Management and Team Activities

Centre Management

Ir Clement LI
Chief Operating Officer

Dr. Gary WONG,
Assistant General Manager

Ms. Jan YEUNG,
Liaison & Marketing Manager

Ms. Joyce CHAN,
Senior Administrative Manager

Research Program Managers

Dr. Vincent NG,
Senior Programme Manager,
Senior Research Fellow

Mr. Fiske LIN
Assistant Programme Manager

Dr. Rainbow LEE,
Programme Manager

Dr Jenny HUANG,
Assistant Programme Manager

Dr. Tom CHAN
Senior Programme Manager

Happy CNY 2023 welcome at the office

Afternoon Tea Party for Christmas 2023

Group hike in the Shing Mun Country Park

20/10/23, we organized a 'thank-you' gathering at the office for Prof. Yung, for his end of service as Director and CEO of CAiRS. Prof. Yung had the momentous task of laying the foundations for CAiRS and to see through its early growth. We will continue to go from strength to strength in the future to come.

Corporate Information

Useful Contact Information

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Telephone Number:	(+852) 2612 5161
Official Website:	https://www.cairs.hk/

Our Laboratories

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

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

Find us at LinkedIn:
https://www.linkedin.com/company/cairshk/

Find us at Facebook:
https://www.facebook.com/CAiRSHongKong

Requests for Visits

Contact with our technical experts?

Interested in Sponsoring CAiRS?

Media and Public Relations

General Inquiries

Collaborations and Partnerships?

Drop us an e-mail at:
info@cairs.hk